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THERMAL RESPONSE AND REUSABILITY TESTS OF ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION (RSI) AND CERAMIC TILE RSI SAMPLES AT SURFACE TEMPERATURES TO 1200°F.

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Houston, TX 77058

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AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

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Ten minute exposure tests were performed on samples of an advanced flexible reusable surface insulation (AFRSI) made of a quartz glass fabric and samples of a ceramic tile resuable surface insulation (RSI). Tests were performed at free-stream Mach number 10 with a total pressure and temperature of 1200 psia and 2150°R, respectively. Samples were inclined to the flow at 25 deg and heated to about 1660°R during exposure.

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NOMENCLATURE

ALPI	Indicated pitch angle at lift-off, deg
AMES SENSOR	Output of radiometer, mv
CONFIG NUMBER	Sample number 1, 2, 3, or 4
CR	Center of Rotation, axial station along tunnel centerline about which the wedge rotates, in.
e_{b_λ}	Black body emissivity at 530°R
ITT	Enthalpy based on stilling chamber total temperature, Btu/lbm
M	Free-stream Mach number
MU	Coefficient of viscosity based on free-stream temperature, lbf-sec/ft^2
P	Free-stream static pressure, psia
PHII	Indicated roll angle, deg
PT	Total pressure measured in the tunnel stilling chamber, psia
Q	Free-stream dynamic pressure, psi
RE	Free-stream unit Reynolds number, ft^{-1}
RHO	Free-stream density, lbm/ft^3
RUN	Data set identification number
SAMPLE POSITION	0 or 180 degrees, 0 denotes small RSI tiles on right side of wedge looking downstream, 180 deg-reversed
TAW	Adiabatic wall temperature, °R
T	Free-stream static temperature, °R
TT	Total temperature measured in the tunnel stilling chamber, °R
TCi	Output of thermocouple i on sample, °R
TR1, TR2	Measured reference temperature at connector, °R

TIMECL	Time at which the wedge reached tunnel centerline, CST
TIMEEXP	Time of exposure to the tunnel flow when data were recorded, sec
TIMEEXPT	Total exposure time for a RUN, sec
TIMEINJ	Elasped time from lift-off to arrival at tunnel centerline, sec
V	Free-stream velocity, ft/sec
WA	Wedge angle with respect to free-stream, deg
X_λ	IR camera spectral response factor
ε	Fabric sample total emissivity
ε_λ	Fabric sample spectral emissivity
λ	Wavelength, microns

SUBSCRIPTS

w	Wedge flow conditions

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E01, Control Number 9E01-00-8, at the request of the National Aeronautics and Space Administration (NASA), Johnson Space Center (JSC), Houston, Tx, for the NASA, Ames Research Center (ARC), Mountain View, Ca. The NASA-JSC project monitor was Mr. Bill Moseley (ES3) and the NASA-ARC project monitor was Mr. Howard Goldstein. The results were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in the von Karman Gas Dynamics Facility (VKF) Hypersonic Wind Tunnel (C) on April 4 and 5, 1979, under ARO Project No. V41C-56.

The test objectives were to determine the thermal response and reusability of Advanced Flexible Resuable Surface Insulation (AFRSI) materials. Sample materials were exposed to a controlled aerothermal environment to obtain performance comparisons between AFRSI and ceramic Resuable Surface Insulation (RSI) tiles.

The samples were exposed to a Mach 3.4 flow with a wedge static pressure of 0.74 psia and a computed recovery temperature of 1982°R. These conditions were obtained by inclining the wedge 25 deg to the tunnel Mach 10 flow with a stagnation pressure of 1200 psia and total temperature of 2150°R.

Inquiries to obtain copies of the test data should be directed to Mr. Bill Mosely, ES3, NASA-JSC, Houston, Tx, 77058. A microfilm record has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel C (Fig. 1) is a closed-circuit, hypersonic wind tunnel with a Mach number 10 axisymmetric contoured nozzle and a 50-in.-diam test section. The tunnel can be operated continuously over a range of pressure levels from 200 to 2000 psia with air supplied by the VKF main compressor plant. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 2260°R) are obtained through the use of a natural gas fired combustion heater in series with an electric resistance heater. The entire tunnel (throat, nozzle, test section, and diffuser) is cooled by integral, external water jackets. The tunnel is equipped with a model injection system, which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel may be found in the Test Facilities Handbook (Ref. 1).

2.2 TEST ARTICLE

Four (4) test articles were furnished by NASA/Ames, photographs of which are presented in Fig. 2. These articles, or samples, were fabricated at NASA/Ames and consisted of various combinations of flexible

reusable surface insulation (FRSI) and ceramic reusable surface insulation (RSI). Shown in Fig. 3 are planform sketches of the test articles denoting the different combinations of insulation used on each sample. Variations among the FRSI samples were the weight of the fabric, the weave of the quilting, and the edge formation. The RSI samples were of different thicknesses and had various silicon coatings applied to their surfaces. The specifics of these variations are beyond the scope of this report, but may be obtained by inquiries directed to the NASA-ARC personnel.

All samples were bonded to an 1/8-in. aluminum plate which in turn was attached to a Bakelite® plate of variable thickness to maintain a total thickness of 1.50-in. Presented in Fig. 4 are an installation photograph and sketch of a sample mounted on a steel wedge designed for materials testing. Three rows of steel balls (0.078-in. diam) were welded to the steel surface 3-in. aft of its leading edge to produce a turbulent boundary-layer over the samples. From prior testing with this wedge, it is known that a turbulent boundary-layer exists ahead of the sample at wedge angles of 12 deg or greater.

2.3 TEST INSTRUMENTATION

2.3.1 Test Conditions

Tunnel C stilling chamber pressure is measured with a 500- or 2500-psid transducer referenced to a near vacuum. Based on periodic comparisons with secondary standards, the accuracy (a bandwidth which includes 95-percent of the residuals, i.e. 2σ deviation) of the transducers is estimated to be within ±0.16 percent of pressure or ±0.5 psi, whichever is greater, for the 500-psid range and ±0.16 percent of pressure or ±2.0 psi, whichever is greater, for the 2500-psid range. Stilling chamber temperature measurements are made with Chromel®-Alumel® thermocouples which have an uncertainty of ±(1.5°F + 0.375 percent of reading in °F).

2.3.2 Test Data

The sample instrumentation consisted of thermocouples (22 in samples 1, 3, and 4; 23 in sample 2) placed at positions of interest to evaluate the thermal response. The thermocouples were of AWG #36 (0.005 in. diam) platinum/platinum-rhodium (13%) material. The placement of these thermocouples in the samples are shown in Fig. 5. The precision of these thermocouple measurements is ±3 to 4 deg from room temperature to 1200°F.

Also a user-supplied radiometer was set up to view a 0.5-in. diam area of the sample surface about 2.8-in. back of the sample leading edge and on the wedge centerline. This instrument recorded the total radiant heat flux emitted from the sample area and its output was recorded in millivolts. The precision of the recorded signal is estimated to be ±0.015 millivolts.

The VKF infrared system was used to map the sample surface temperature. The system utilizes an AGA Thermovision® 680 camera which scans at a rate of 16 frames per second. The camera detector is sensitive to infrared radiation in the 2 to 6 micron wavelength band. Camera calibrations are performed with a standard black body reference

source and have consistently been within ±1 percent of the camera manufactuer's calibration and are repeatable within ±1 percent in absolute temperature. A description of the VKF system is given in Ref. 2.

The output of the IR camera was displayed on a color TV monitor in real time and at selected times the monitor was photographed with a 70mm color still camera.

Sixteen mm color movies were taken of the samples intermittently during the run and shadowgraphs were taken after the samples reached the tunnel centerline and at selected wedge angles to record the flowfield characteristics.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

3.1.1 General

The test was conducted at a nominal Mach number of 10 and the stream conditions were maintained at approximately the values listed below.

M	PT, psia	TT, °R	Q, psia	P, psia	RE x 10^{-6}/ft	M_w	P_w, psia	TAW_w, °R
10.14	1200	2150	1.75	0.024	1.18	3.4	0.74	1982.0

A test summary showing all configurations tested and the variables for each is presented in Table 1.

In the VKF continuous flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, and the model is injected into the airstream, and the fairing doors are closed. After the data are obtained, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. The sequence is repeated for each configuration change.

3.1.2 Data Acquisition

The procedure for obtaining the test measurements changed during the progress of the test. Initially there was concern for the survivability of the cloth samples at wedge angles as large as 25 deg; hence, the wedge was injected at zero pitch and rotated to 25 deg, observing the sample (#3 was used) for any indication of failure, and reversing the procedure for retraction. No indications of failure were observed. Next the sample

was injected and retracted at 25 deg and again observed for indications of failure. No problems were encountered during injection but on retraction the top layer of the cloth sample was blown away (see Fig. 6(a)). It appears the turbulence encountered during retraction through the tunnel wall boundary layer at such a large angle was too severe. A possible explanation of the absence of failure during injection through the same turbulence is that the increased fabric temperature decreased its strength prior to retraction. Consequently, the initial procedure described above was adopted for the remainder of the test.

The samples were exposed to the flow for 10 minutes each time they were injected. The output of all the instrumentation was recorded every 0.5 sec until the wedge reached the 25 deg pitch angle, then data were recorded every 5 sec for the remainder of the run. The IR system TV monitor was observed, and when the sample surface temperature showed approximately 1200°F a 70mm photograph was taken. Another photograph was taken just prior to retraction.

The samples were observed directly during exposure, and whenever any unusual circumstances developed (fabric tears or loose tiles) the 16mm movie camera was used to record the events. In addition, the injection cycle of each run was recorded on 16mm film.

After retraction, the sample was cooled by a tank door nozzle and adjustable mainfolds on each side using high pressure air. Also the sample support wedge has internal water cooling passages which aided in cooling the sample. Whenever the sample aluminum support plate cooled to 150°F, the sample was injected for another run or replaced by another sample. Any damage to the samples was photographed using a 70mm camera prior to continued testing (see Fig. 6(b)).

Each exposure is termed a run and all the data obtained are identified in the data tabulations by run number. The sample tested during each run is listed in Table 1.

3.2 DATA REDUCTION

The tabulated data for each run includes a listing of tunnel conditions and sample information necessary to use the data. Beneath this listing the sample temperatures and radiometer output are listed at selected times. The wedge angle is included in this listing to document its variation with time. A description of the computation procedures used to produce the data follows.

3.2.1 IR System Photographs of Sample Surface Temperature

The calibration of the IR system itself is detailed in Ref. 2 and the only other information required to obtain the sample surface temperature is the surface emissivity.

A representive sample of the fabric insulation was examined to determine its emissivity over the range of 3 to 6 microns. The results are presented in Fig. 7. The sample total emissivity was computed by the equation

$$\varepsilon = \frac{\int_\lambda \varepsilon_\lambda\, e_{b_\lambda}\, X_\lambda\, d\lambda}{\int_\lambda e_{b_\lambda}\, X_\lambda\, d\lambda} \qquad (1)$$

where

ε_λ = is the sample spectral emissivity from Fig. 7 at 530°R

e_{b_λ} = is the black body spectral emissivity at 530°R

X_λ = is the IR camera spectral response factor obtained from AGA data.

Both e_{b_λ} and $e_{b_\lambda} * X_\lambda$ variations with wavelength over the range of interest are presented in Fig. 8(a) and $\varepsilon_\lambda * e_{b_\lambda} * X_\lambda$ variations are shown in Fig. 8(b). The values of the integrals are shown in the figures; from these the sample total emissivity was computed to be 0.62. For this emissivity, the color calibration with temperature for the photographs off the IR system TV monitor is listed in Table 2.

3.2.2 Sample Temperatures

Because the VKF thermocouple hookup network does not include provisions for platinum/platinum-rhodium (13%) thermocouples and the expense of platinum wire, the thermocouple leads were only about 12-in. long and terminated at a 50-pin connector inside the wedge support. Copper leads were used from the other side of the connector to the instrumentation. The output of the sample thermocouples was dependent upon the connector temperature with this type hookup; hence, two positions on the connector were used to measure the connector (reference) temperature using Chromel®-Alumel® thermocouple wire. The reference temperatures were measured with direct-readout instruments in °F.

The total output of each sample thermocouple was computed by first calculating the equivalent platinum millivolt output of the reference thermocouple using the following equation

$$\begin{aligned} E_R &= 0.42282 + (2.66830 \times 10^{-3})\ \mathrm{TR1} \\ &+ (4.49139 \times 10^{-6})\ (\mathrm{TR1})^2 - (3.50748 \times 10^{-9})(\mathrm{TR1})^3 \\ &+ (1.40615 \times 10^{-12})\ (\mathrm{TR1})^4 \end{aligned} \qquad (2)$$

where

E_R = equivalent millivolt output of a platinum thermocouple at temperature TR1

TR1 = measured reference temperature in °F

A second reference temperature (TR2) was used as a redundant measurement. The reference millivolts (E_R) were added to the output of each platinum thermocouple (E_M) to obtain the total millivolts output of each thermocouple (E_{TC}). The temperature for each platinum thermocouple was then computed from the equation

$$TCi = A0 + A1(E_{TCi}) + A2(E_{TCi})^2 + \ldots + AN(E_{TCi})^N \qquad (3)$$

where the coefficients A0, ..., AN are determined from the following table

Range of E_{TCi}, mv	A0	A1	A2	A3	A4	A5
$-0.422 \le E_{TC} \le 1.175$	591.727	270.981	-11.8644	53.7323	-37.7430	11.9930
$1.175 \le E_{TC} \le 5.604$	605.398	234.610	-17.7323	2.18924	-0.122826	--
$5.604 \le E_{TC} \le 11.024$	657.117	192.452	-3.8197	0.0687992	--	--

and i denotes the TC number.

The connector reference temperatures (TR1 and TR2) as well as the output of the Ames radiometer were printed out as measured.

3.3 UNCERTAINTY OF MEASUREMENTS

3.3.1 General

The accuracy of the basic measurements (PT and TT) was discussed in Section 2.3. Based on repeat calibrations, these errors were found to be

$$\frac{\Delta PT}{PT} = 0.0016 = 0.16\%, \quad \frac{\Delta TT}{TT} = 0.004 = 0.4\%$$

Uncertainties in the tunnel free-stream parameters and the model temperatures were estimated using the Taylor series method of error propagation, Eq. (4),

$$(\Delta F)^2 = \left(\frac{\partial F}{\partial X_1}\Delta X_1\right)^2 + \left(\frac{\partial F}{\partial X_2}\Delta X_2\right)^2 + \left(\frac{\partial F}{\partial X_3}\Delta X_3\right)^2 \ldots + \left(\frac{\partial F}{\partial X_n}\Delta X_n\right)^2 \qquad (4)$$

where ΔF is the absolute uncertainty in the dependent parameter $F = f(X_1, X_2, X_3 \ldots X_n)$ and X_n are the independent parameters (or basic measurements). ΔX_n are the uncertainties (errors) in the independent measurements (or variables).

3.3.2 Test Conditions

The accuracy (based on 2σ deviation) of the basic tunnel parameters, PT and TT, (see Section 2.3) and the 2σ deviation in Mach number determined from test section flow calibrations were used to estimate uncertainties in the other free-stream properties using Eq. (1). The computed uncertainties in the tunnel free-stream conditions are summarized in the following table.

Uncertainty, (±) percent of actual value				
M	M	P	Q	RE
10.14	1.0	5.3	3.7	2.3

The uncertainty of the wedge angle is estimated to be ±0.1 deg.

3.3.3 Test Data

The uncertainties of the test data parameters are summarized in the following table

Data Type	Uncertainty, (±) percent of actual value
IR Color Interface Temperature	1.00
Ames Radiometer Output	0.14
Sample Temperature @ 1660°R	0.35
Reference Temperature @ 575°R	0.67

4.0 DATA PACKAGE PRESENTATION

Tabulated results and plotted data were furnished to the test sponsor in a Data Package. Samples of these data are presented in Appendix III.

Some of the sample temperature variations with time shown in the plots are due to the wedge angle variations with time. Therefore, as an aid to the interpretation of the plots shown herein, the wedge angle variation for run 26 is included with the data plots. The wedge angle variations for each run are listed on the tabulated data.

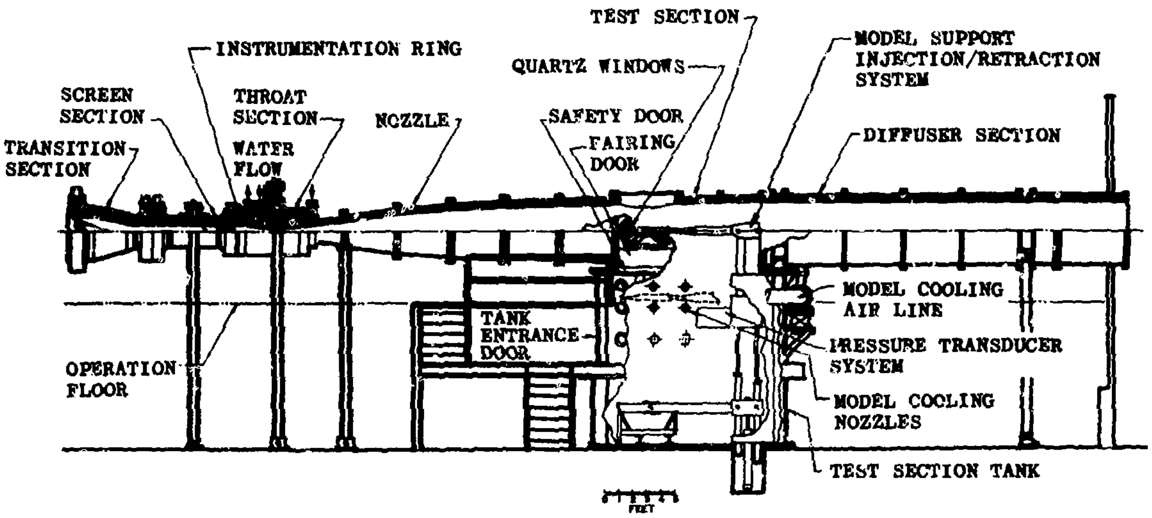
REFERENCES

1. Test Facilities Handbook (Tenth Edition). "von Karman Gas Dynamics Facility, Vol. 3" Arnold Engineering Development Center, May 1974.

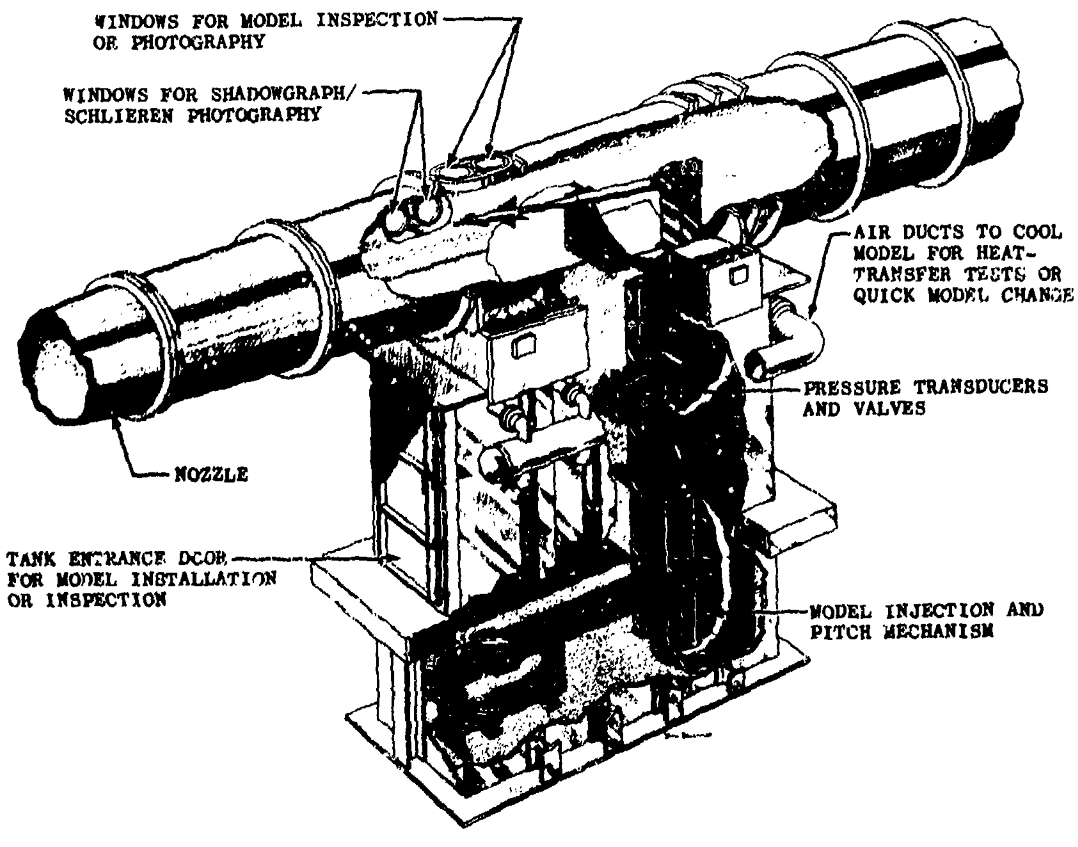
2. Boylan, D. E, et al, "Measurements and Mapping of Aerodynamic Heating Using a Remote Scanning Camera in Continuous Flow Wind Tunnels," AIAA Paper 78-799, April 1978.

APPENDIX I

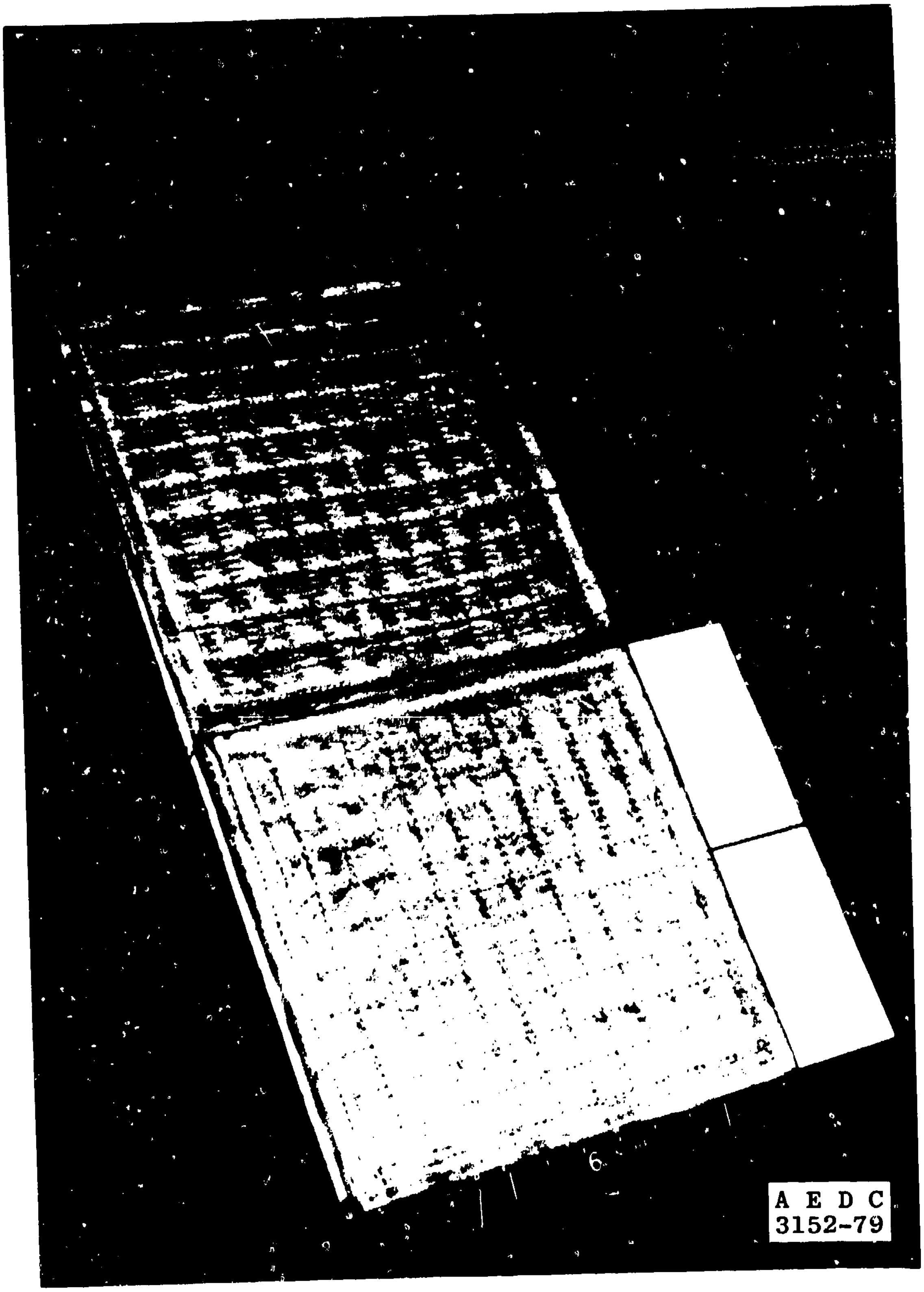
ILLUSTRATIONS



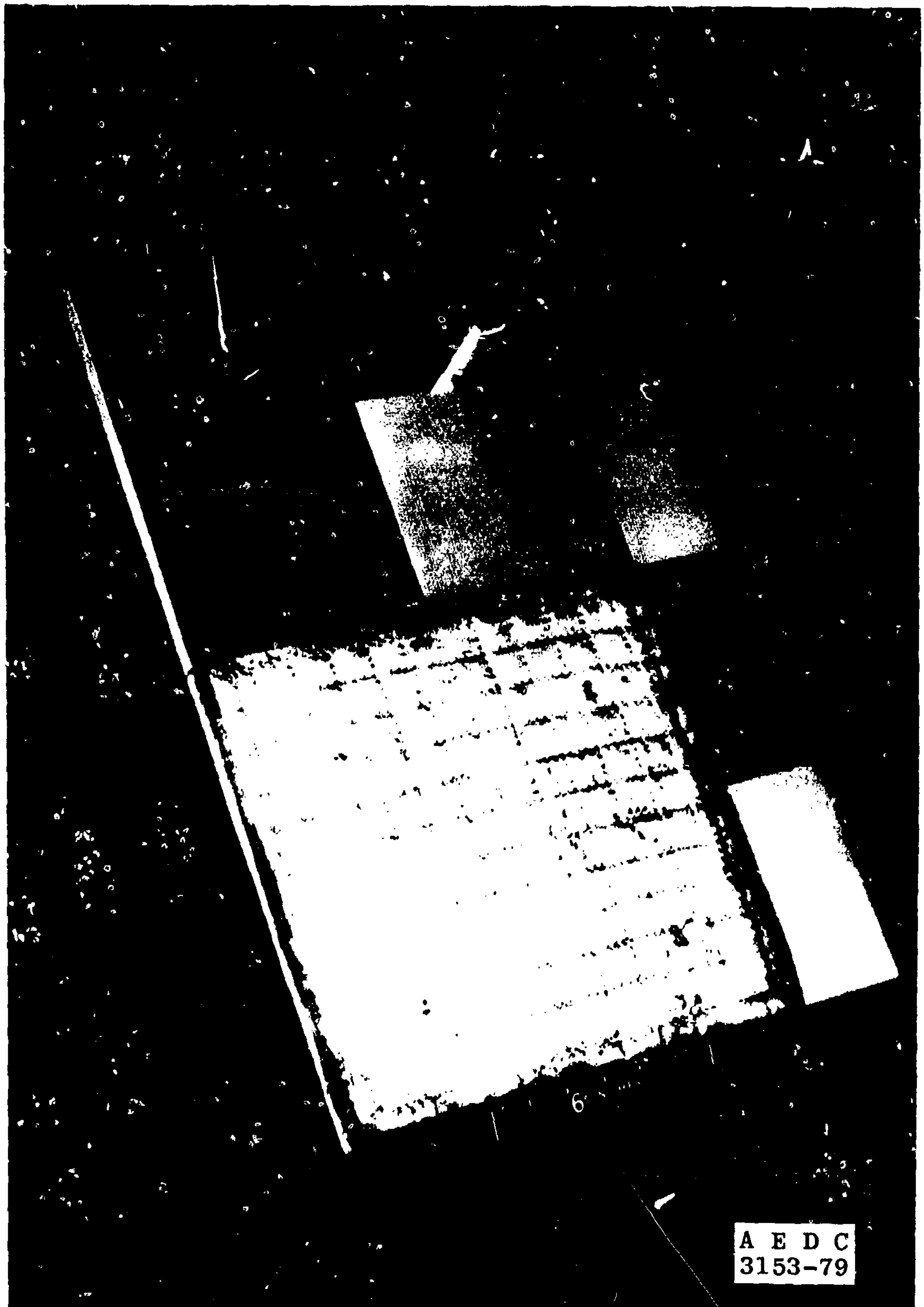
a. Tunnel assembly



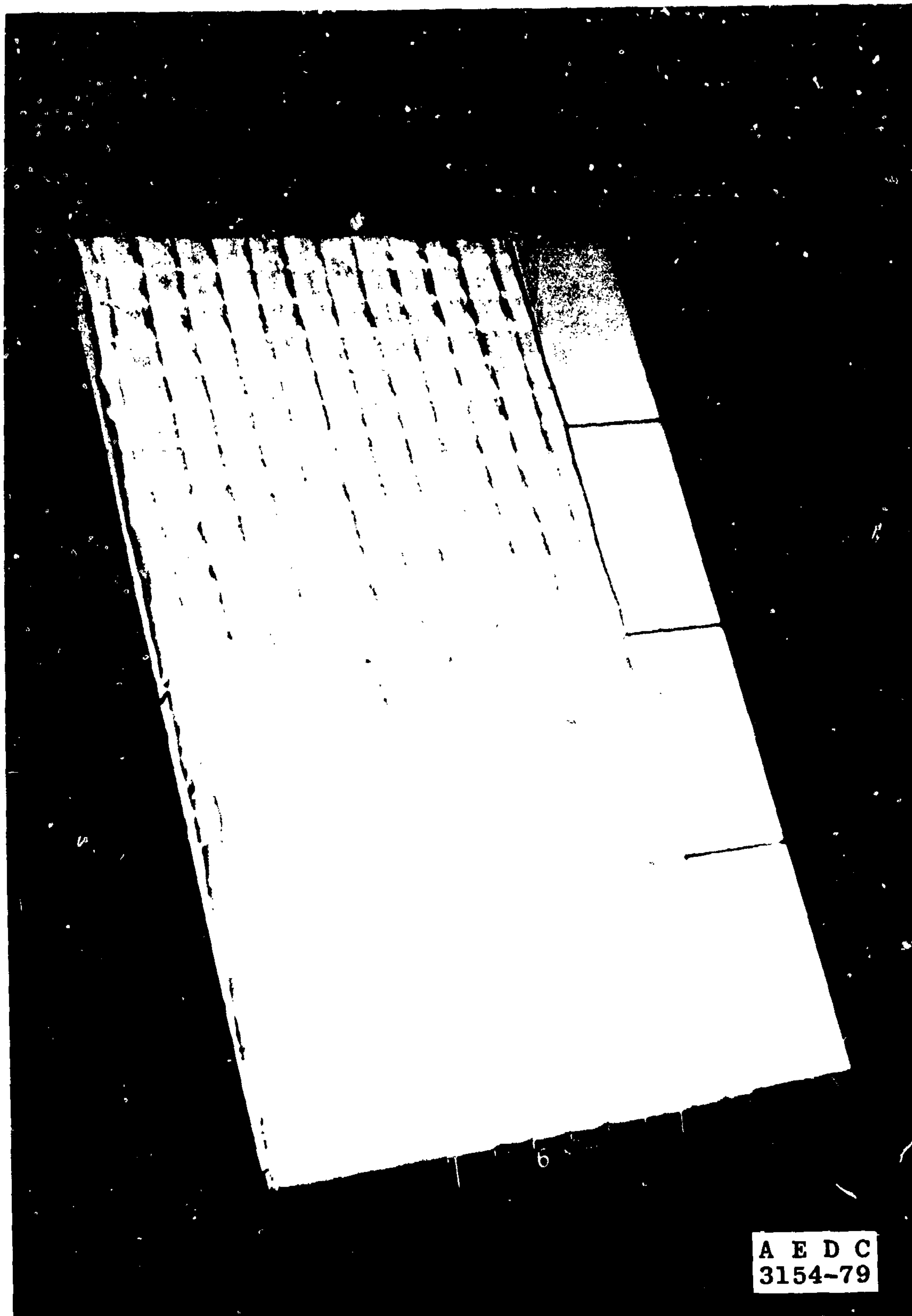
b. Tunnel test section
Fig. 1 Tunnel C



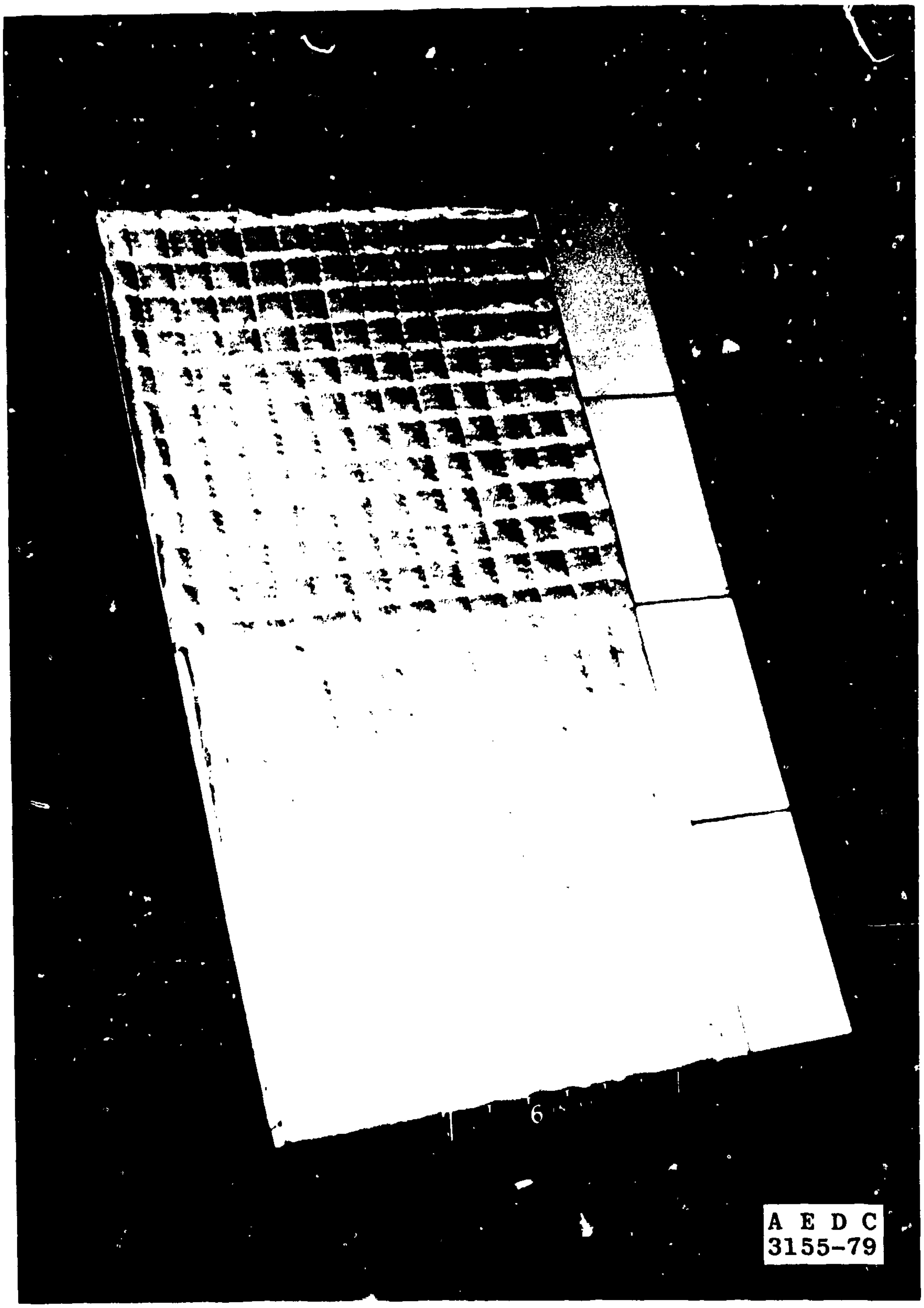
a. No. 1
Fig. 2 Sample Photographs



b. No. 2
Fig. 2 Continued

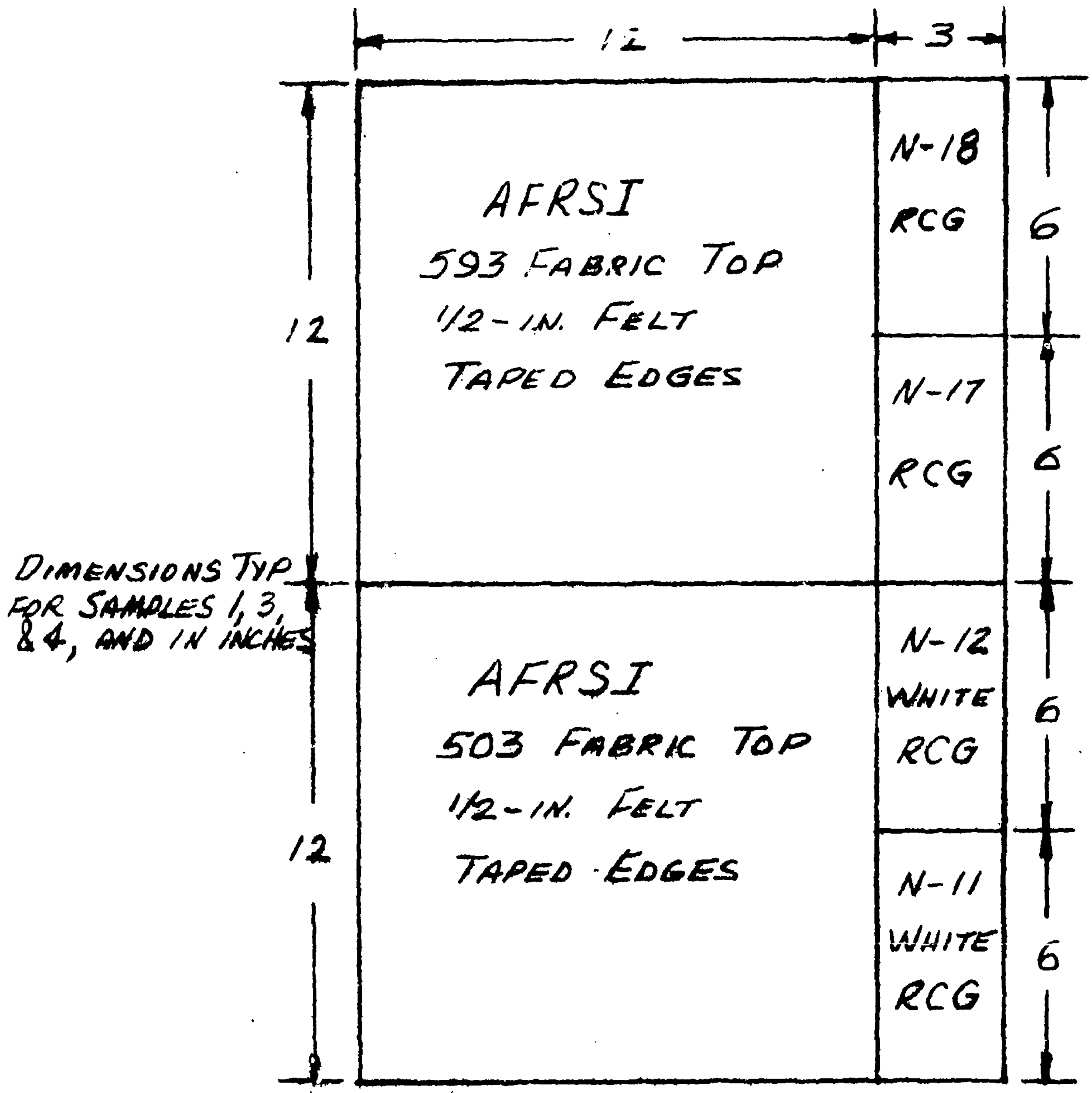


c. No. 3
Fig. 2 Continued



d. No. 4
Fig. 2 Concluded

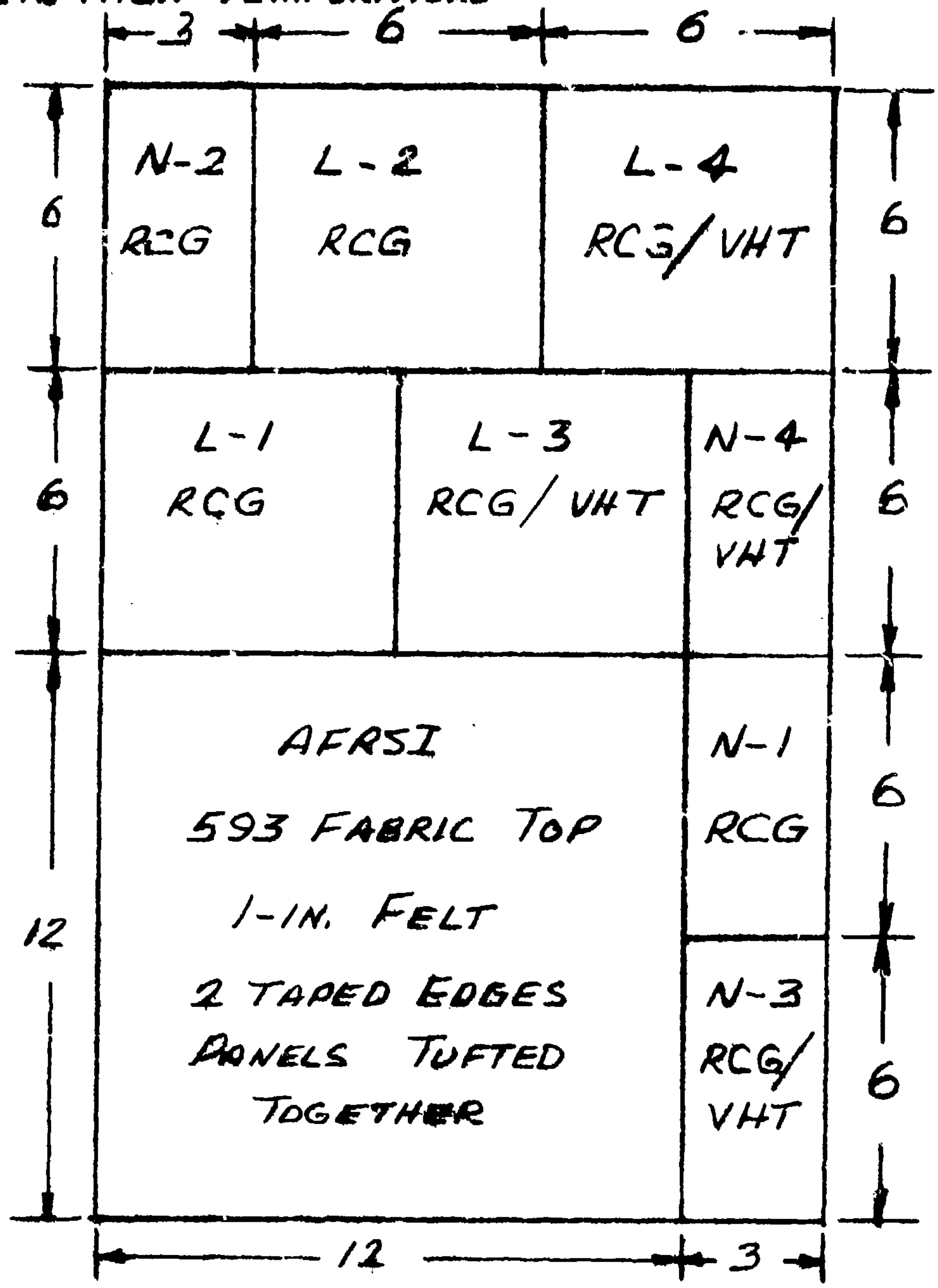
AFRSI = ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION
RCG = REACTION CURED GLASS



(a) No. 1

Fig. 3 Sample Details

AFRSI = ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION
RCG = REACTION CURED GLASS
VHT = VERY HIGH TEMPERATURE PAINT

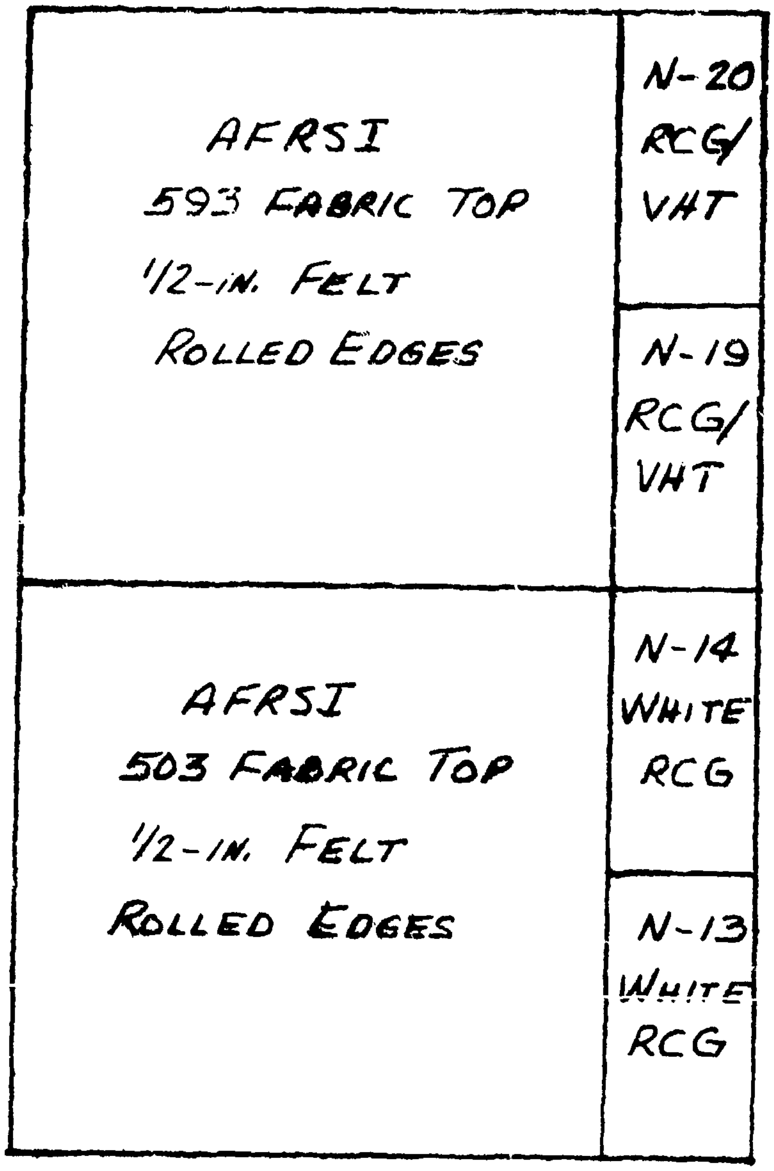


(b) No. 2

ALL DIMENSIONS IN INCHES

Fig. 3 Continued

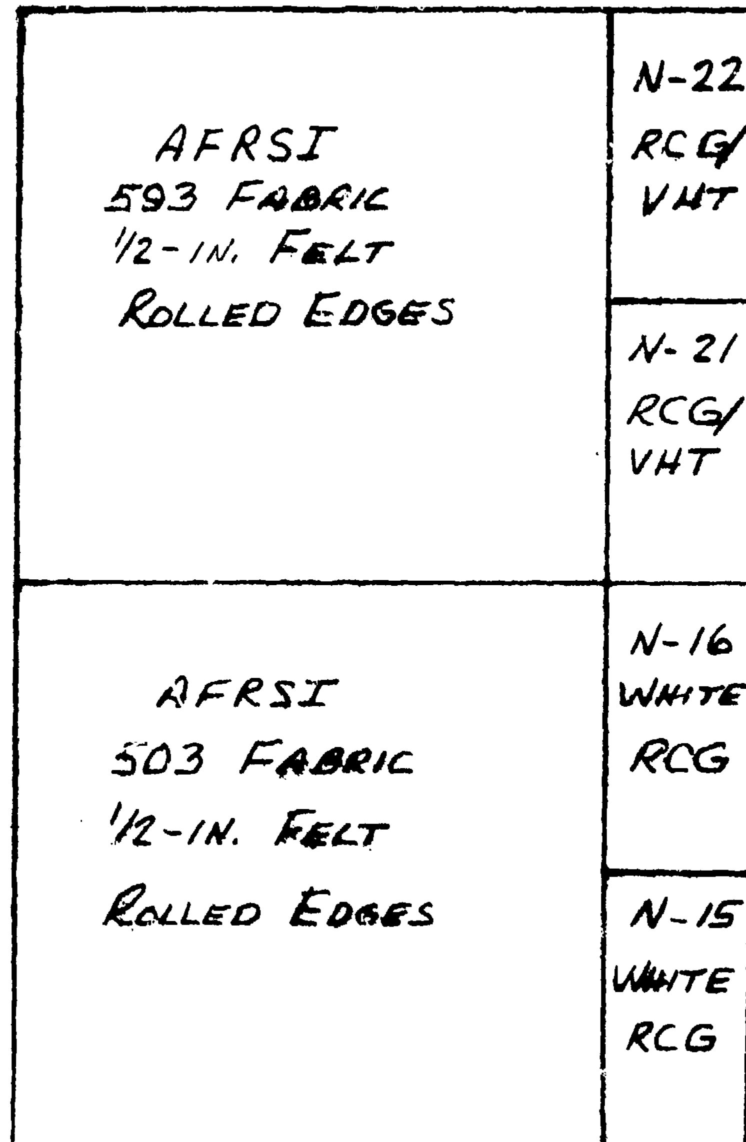
AFRSI = ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION
RCG = REACTION CURED GLASS
VHT = VERY HIGH TEMPERATURE PAINT



(c) No. 3

Fig. 3 Continued

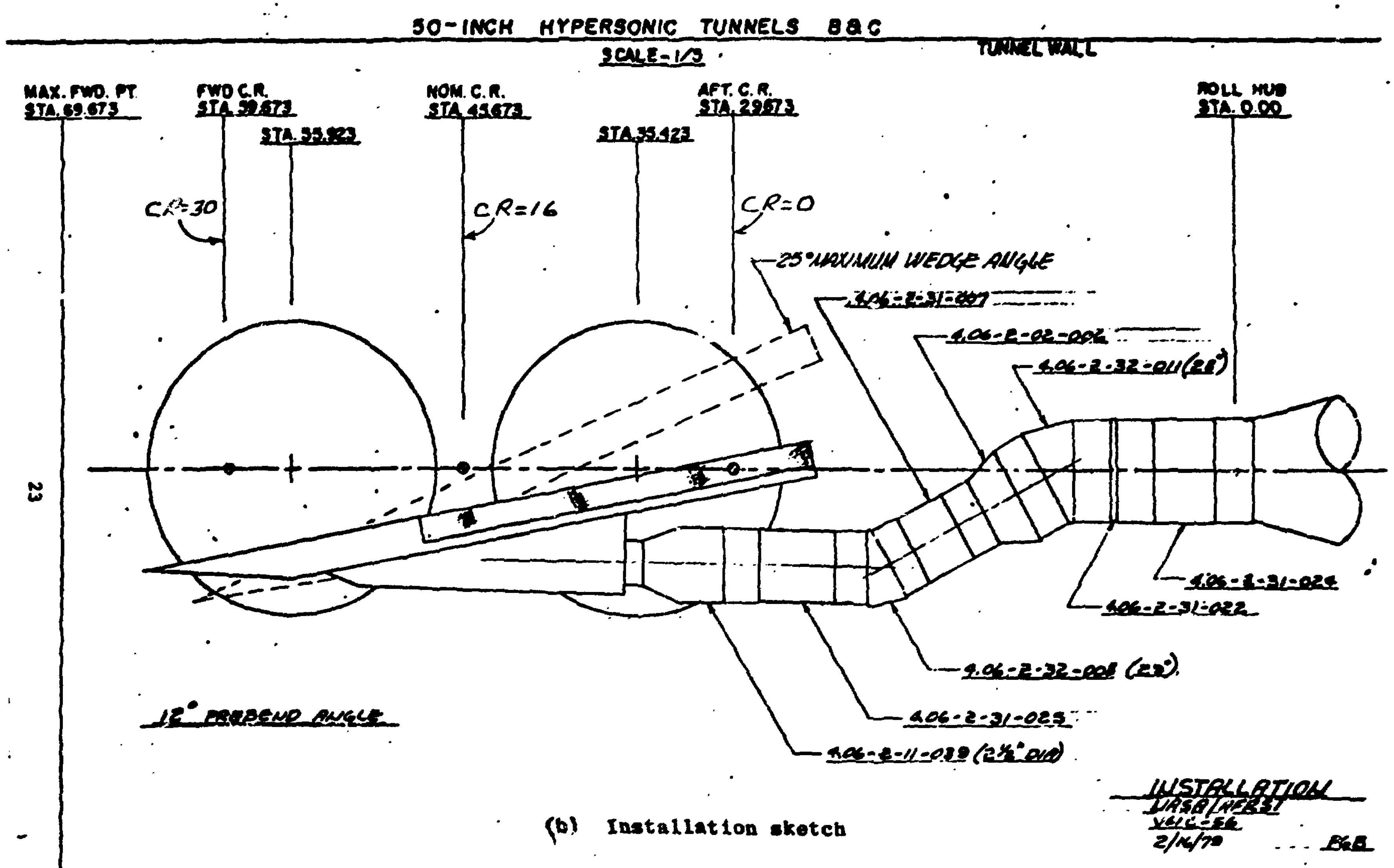
AFRSI = ADVANCED FLEXIBLE REUSABLE SURFACE INSULATION
RCG = REACTION CURED GLASS
VHT = VERY HIGH TEMPERATURE PAINT



(d) No. 4

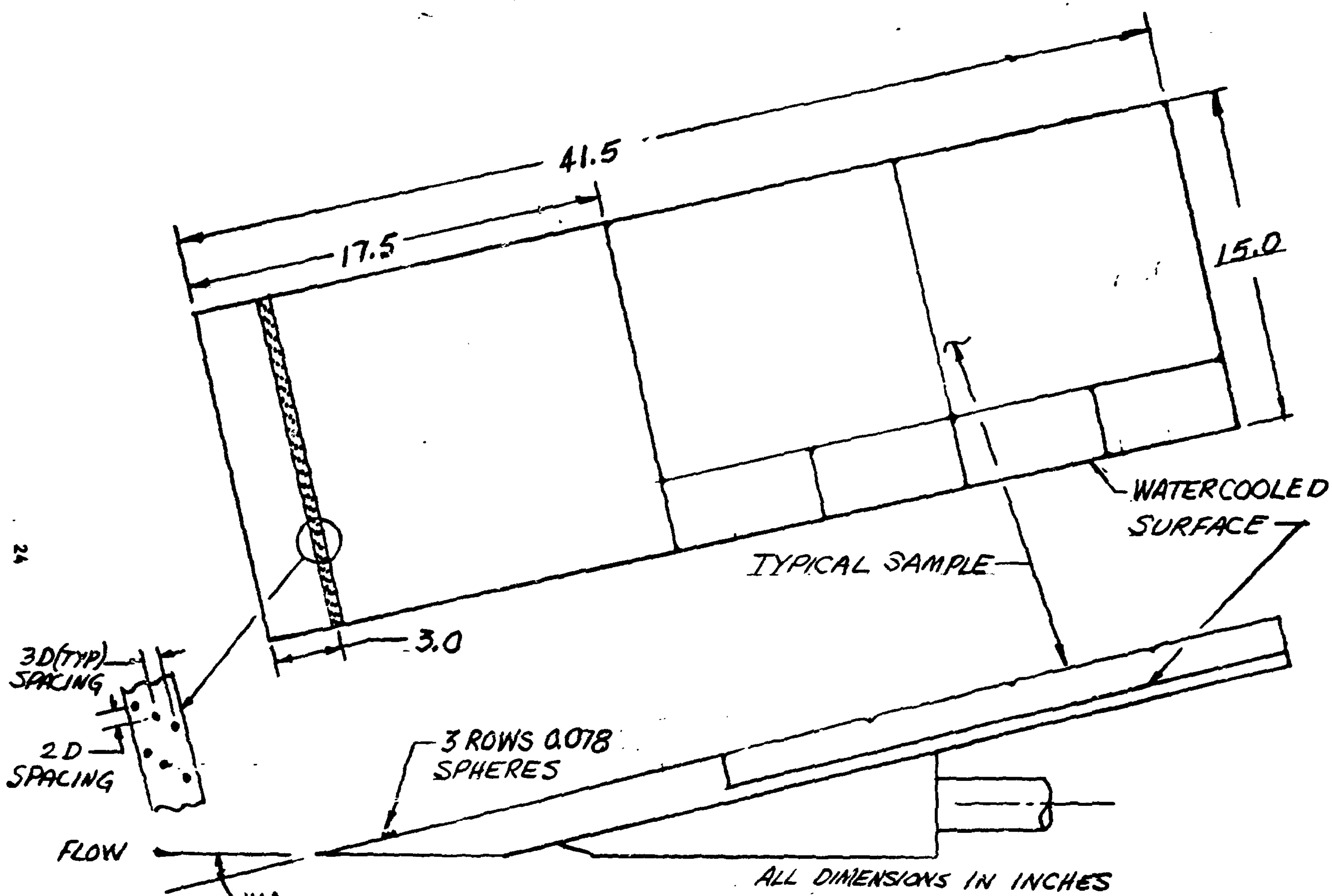
Fig. 3 Concluded

a. Installation Photograph
Fig. 4 Installation Photograph and Sketches



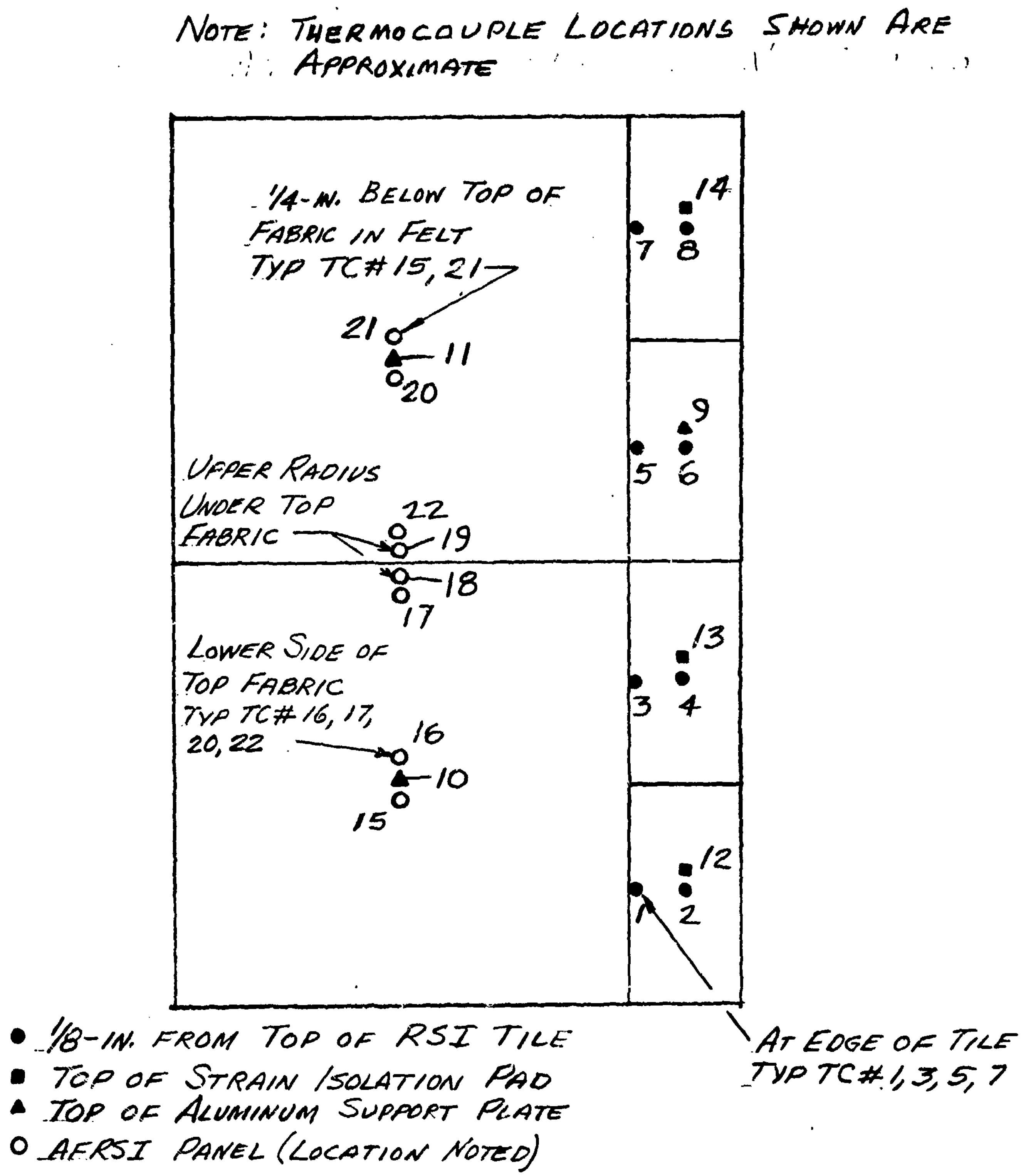
(b) Installation sketch

Fig. 4 Continued



(c) Dimensional sketch

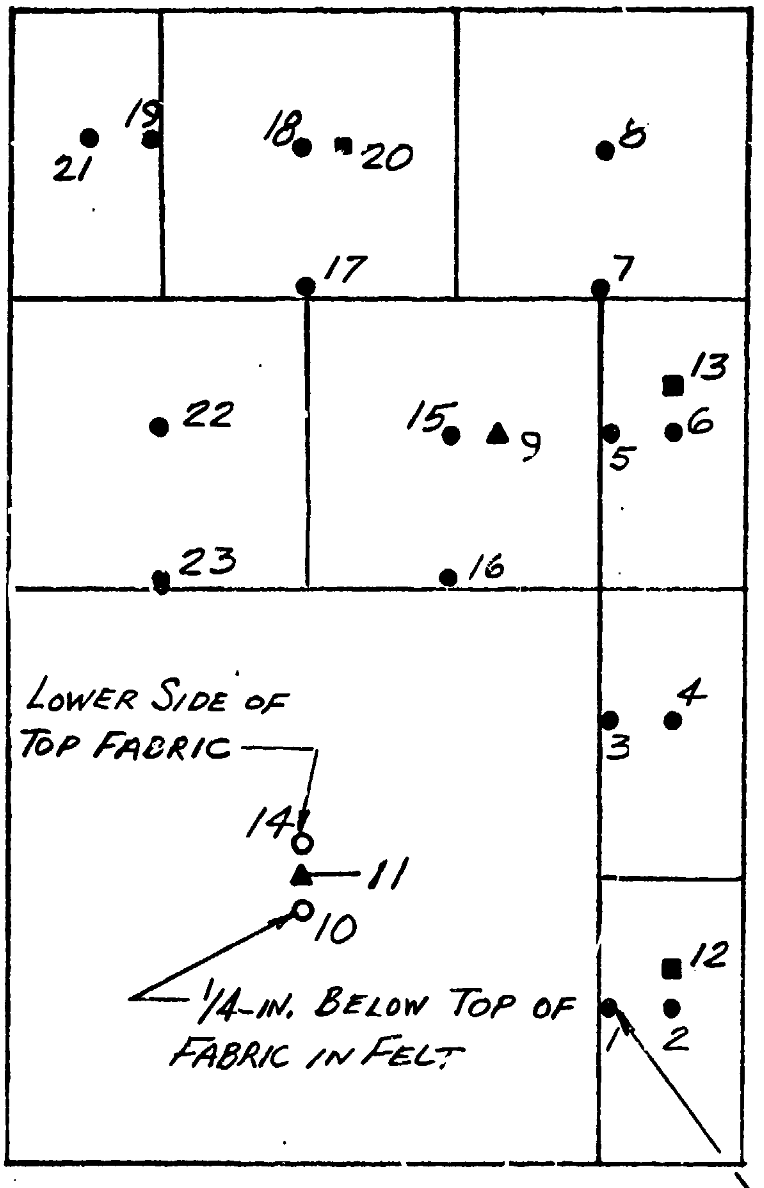
Fig. 4 Concluded



(a) Samples 1, 3, and 4

Fig. 5 Sample Thermocouple Locations

NOTE: THERMOCOUPLE LOCATIONS SHOWN ARE APPROXIMATE.



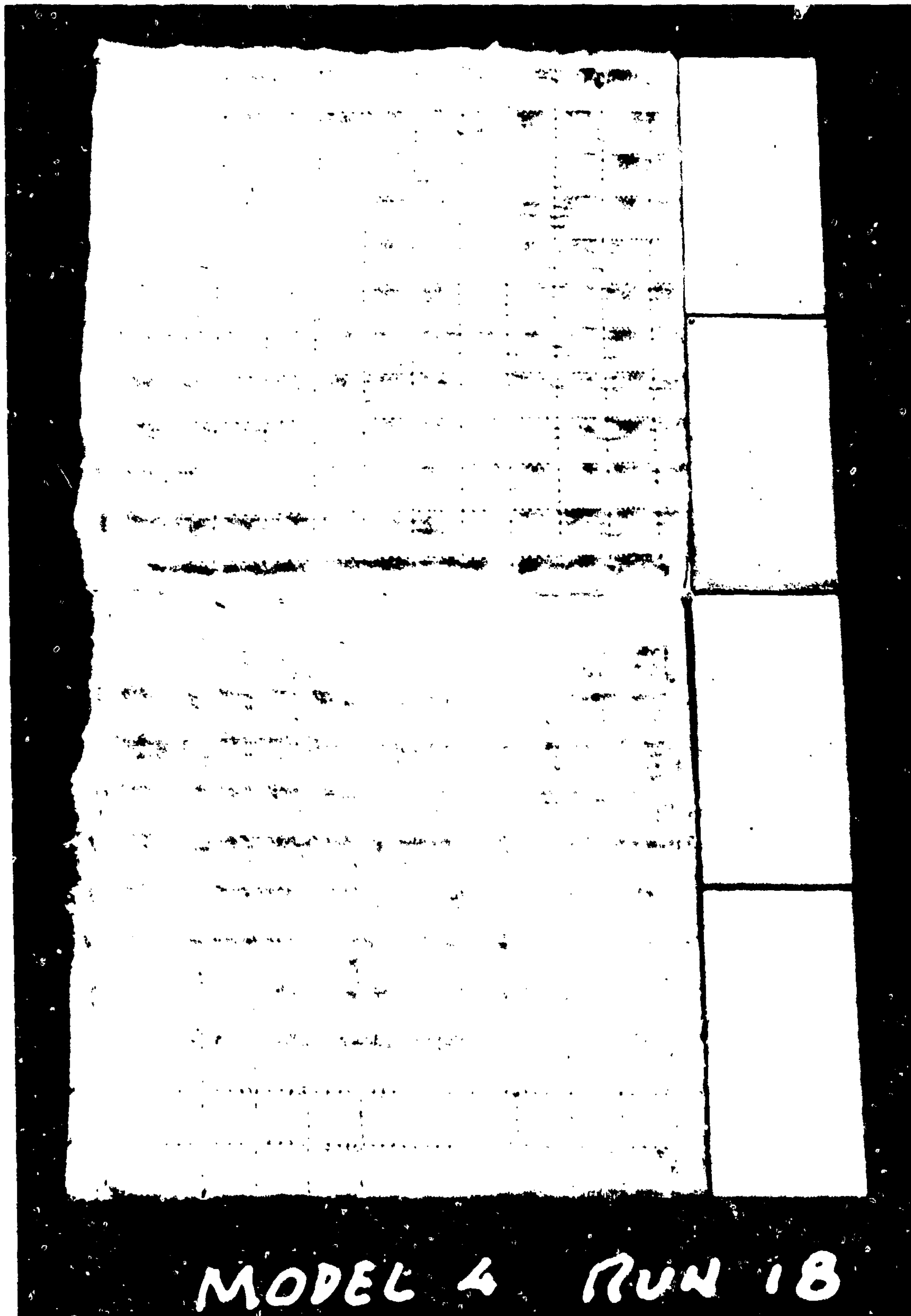
AT EDGE OF TILE TYP TC# 1, 3, 5, 7, 16, 17, 19, 23

● 1/8-IN. FROM TOP OF RSI TILE
■ TOP OF STRAIN ISOLATION PAD
▲ TOP OF ALUMINUM SUPPORT PLATE
○ AFRSI PANEL (LOCATION NOTED)

(b) Sample 2

Fig. 5 Concluded

a. Sample 3 after Run 1
Fig. 6 Photographs of Damaged Samples



b. Sample 4 after Run 18
Fig. 6 Concluded

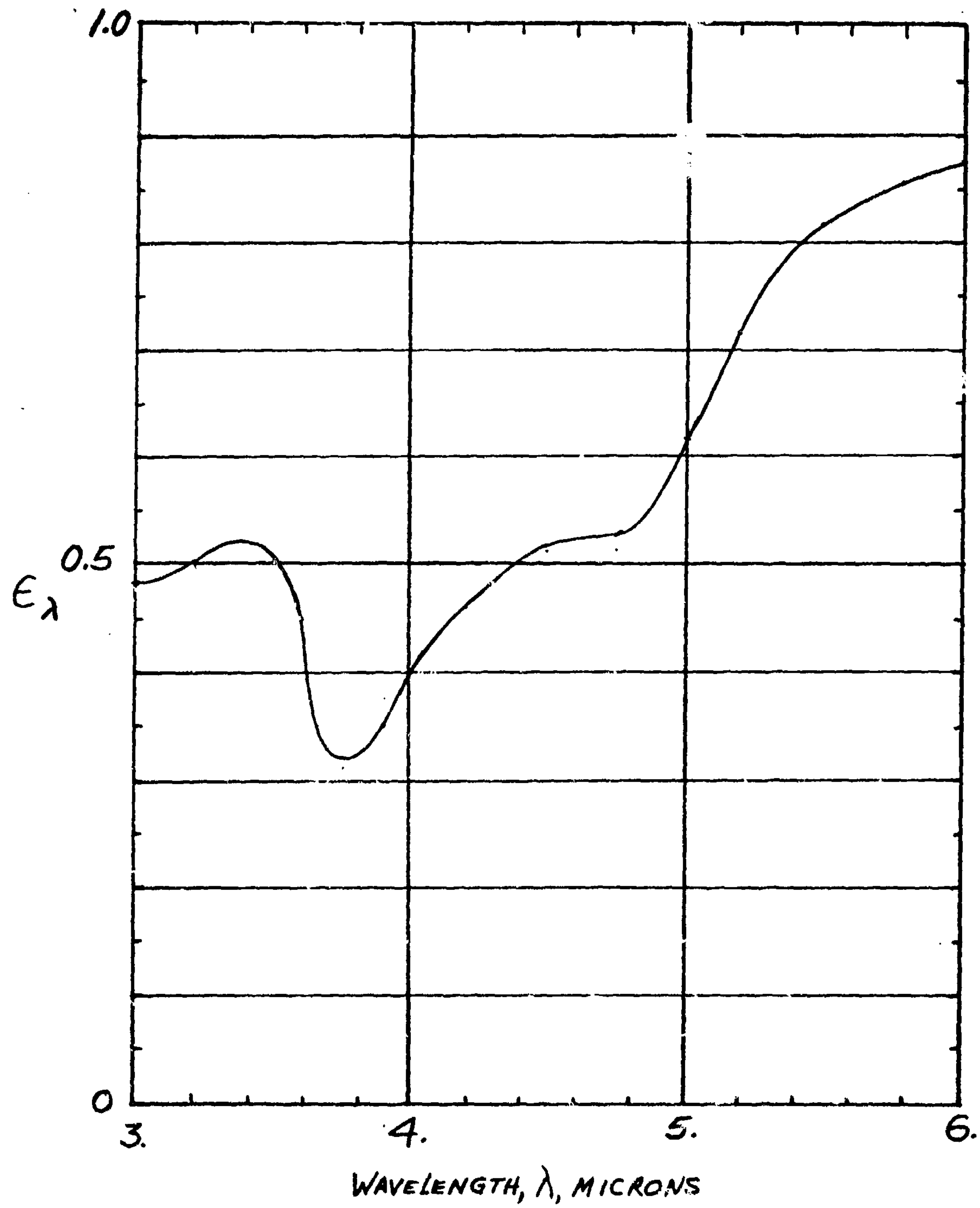
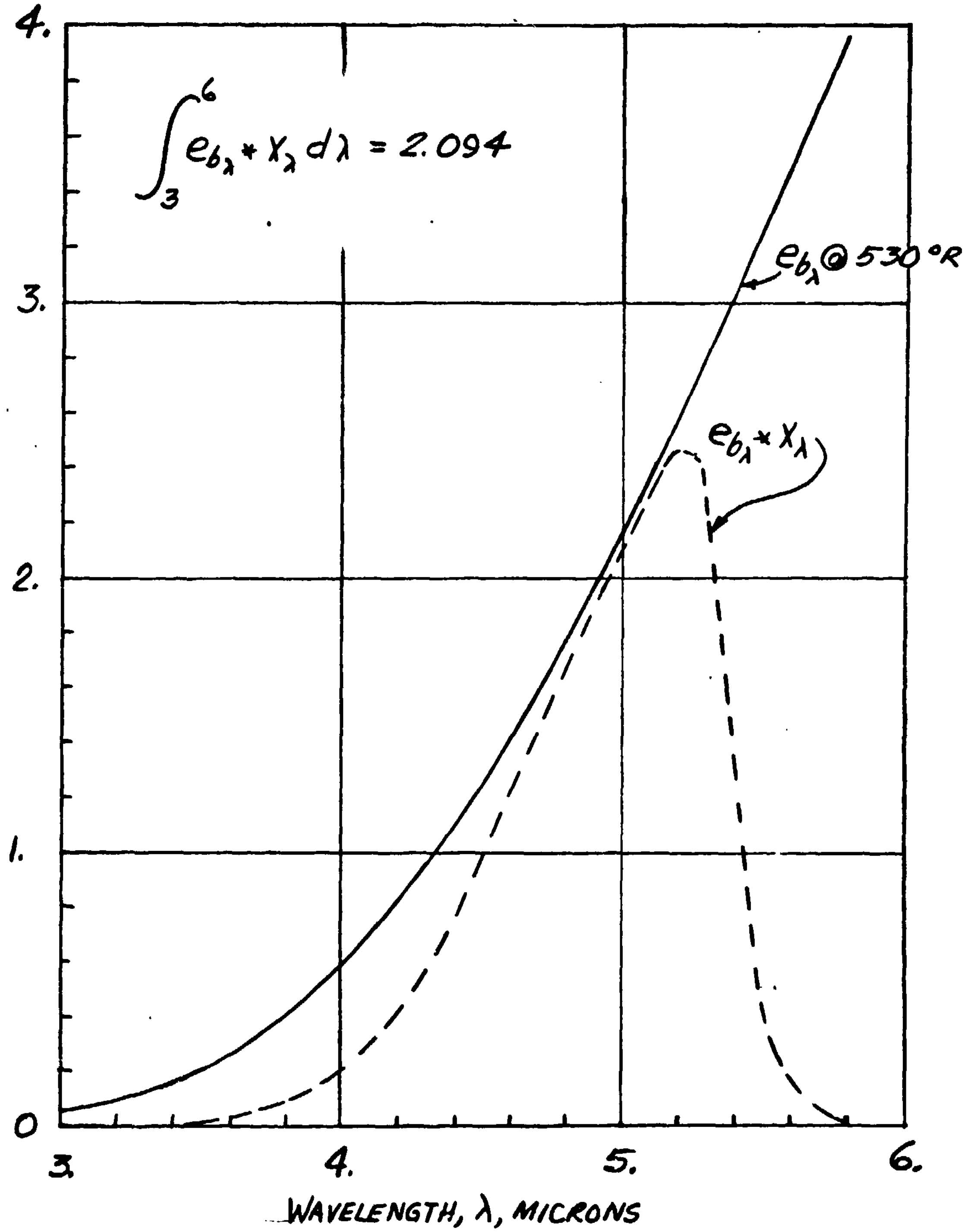
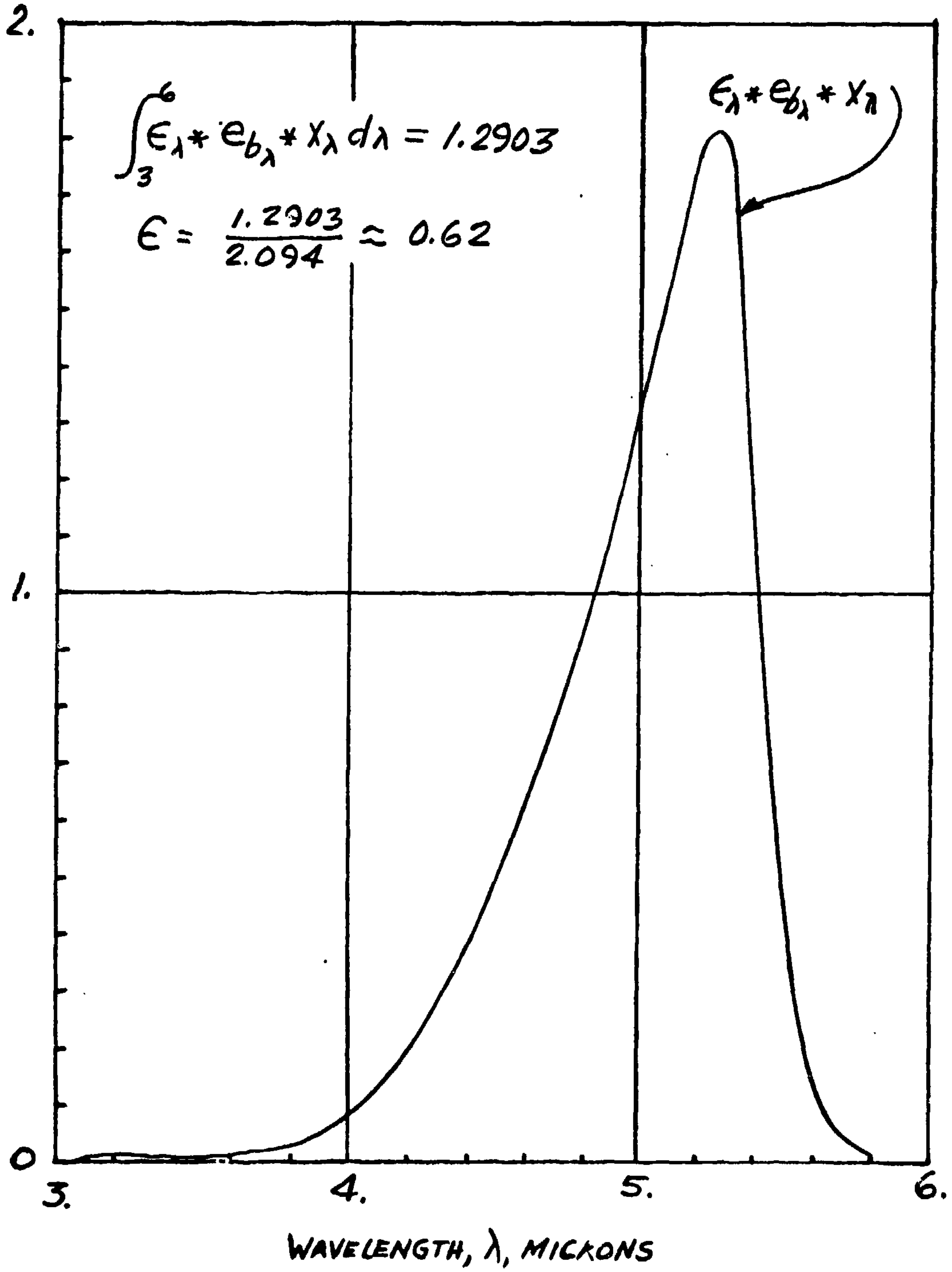


Fig. 7 Sample AFRSI Spectral Emissivity



(a) Black body emissivity and IR camera response factor

Fig. 8 Black Body and AFRSI Total Emissivity



(b) AFRSI sample total emissivity

Fig. 8 Concluded

APPENDIX II

TABLES

TABLE 1

TEST SUMMARY

SAMPLE NUMBER	SAMPLE POSITION, DEG	RUN
1	0	2, 3, 4
2	0	9, 10, 11, 12, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29
3	180	1
4	0	5, 6, 7, 8, 13, 14, 15, 16, 17, 18

TABLE 2

IR SYSTEM COLOR/TEMPERATURE CALIBRATION

IR CAMERA	RUN 1	RUNS 2 - 29
SENSITIVITY	500	200
BLACK LEVEL	0.097	1.216
COLOR NUMBER	TEMPERATURE AT COLOR LOWER LIMIT, ^{o}R	
1	-	1459
2	-	1503
3	754	1544
4	1119	1584
5	1289	1622
6	1418	1658
7	1527	1694
8	1623	1728
9	1712	1762
10	1794	1794

APPENDIX III

SAMPLE DATA

1. Tabulated Data
2. Plotted Data
3. IR System Photograph

ARO, INC. - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/AMES AFPSI MATERIALS TEST

DATE COMPUTED 4-MAY-79
TIME COMPUTED 14:49:28
DATE RECORDED 6-APR-79
TIME RECORDED 4:10: 7
PROJECT NUMBER V41C-56

50 INCH HYPERSONIC TUNNEL C

PAGE 1

RUN	CONFIG NUMBER	SAMPLE POSITION	M NUMBER	PT,PSIA	TT,DEG R	ALPI (DEG)	PHII (DEG)	CR (INCHES)
26	2	0	10.14	1194.90	2142.7	11.60	199.88	25.00

T (DEG R)	P (PSIA)	Q (PSIA)	V (FT/SEC)	RHO (LBM/FT3)	MU (LBF-SEC/FT2)	RE (FT-1)	ITT (BTU/LBM)	TIMEINJ (SEC)	TIMECL (HOUR MIN SEC MSEC)	TIMEEXPT (SEC)
105.7	0.024	1.73	5109.8	6.172E-04	8.503E-08	1.193E+09	5.457E+02	6.01	4 10 35 232	680.26

WEDGE ATTITUDE AND TEMPERATURE HISTORY

TIMEEXP (SEC)	WA (DEG)	TC1 (DEG R)	TC2 (DEG R)	TC3 (DEG R)	TC4 (DEG R)	TC5 (DEG R)	TC6 (DEG R)	TC7 (DEG R)	TC8 (DEG R)	TC9 (DEG R)	TC10 (DEG R)	TC11 (DEG R)	TC12 (DEG R)
1.1	0.36	551.	547.	552.	546.	545.	559.	545.	534.		597.	601.	
2.1	0.42	554.	552.	558.	553.	548.	573.	547.	540.		597.	601.	
3.1	0.40	559.	555.	566.	557.	551.	582.	553.	544.		597.	601.	
4.1	0.40	564.	559.	572.	562.	553.	589.	560.	548.		597.	601.	
5.1	0.40	569.	564.	580.	567.	557.	593.	566.	553.		597.	601.	
6.1	0.39	574.	567.	586.	570.	561.	601.	573.	559.		597.	601.	
7.1	0.39	578.	571.	592.	575.	564.	606.	579.	562.		597.	601.	
8.1	0.39	582.	575.	599.	579.	567.	610.	584.	568.		597.	601.	
9.1	0.39	587.	578.	604.	584.	570.	617.	590.	573.		597.	600.	
10.1	0.39	591.	582.	609.	588.	574.	622.	597.	576.		597.	601.	
15.1	0.39	608.	600.	634.	607.	588.	644.	620.	598.		596.	599.	
20.1	0.39	623.	616.	655.	625.	602.	664.	638.	618.		596.	599.	
30.1	6.40	685.	663.	758.	682.	655.	741.	833.	685.		596.	599.	
40.1	6.96	875.	781.	1049.	859.	912.	958.	1104.	843.		596.	598.	
50.1	14.18	1137.	942.	1178.	1019.	1107.	1099.	1269.	975.		601.	597.	
60.1	24.26	1412.	1151.	1297.	1202.	1316.	1281.	1539.	1137.		620.	596.	
71.3	24.53	1494.	1226.	1360.	1278	1393.	1356.	1578.	1211.		641.	595.	
81.3	24.52	1530.	1278.	1416.	1328.	1445.	1396.	1594.	1266.		683.	595.	
90.7	24.51	1544.	1303.	1445.	1351.	1469.	1414.	1602.	1292.		728.	595.	
101.3	24.49	1550.	1319.	1462.	1365.	1483.	1422.	1605.	1311.		771.	595.	
CAMERA NO. 1, TAKEN AT 121.3 SECONDS													
121.3	24.47	1558.	1339.	1480.	1381.	1496.	1435.	1610.	1333.		840.	593.	
151.3	24.47	1565.	1358.	1495.	1397.	1506.	1446.	1614.	1353.		918.	593.	
201.2	24.45	1570.	1378.	1508.	1413.	1512.	1456.	1616.	1371.		1006.	593.	
301.3	24.44	1573.	1402.	1519.	1429.	1513.	1468.	1618.	1388.		1109.	605.	
401.2	24.43	1577.	1417.	1528.	1438.	1513.	1474.	1620.	1397.		1165.	622.	
501.2	24.42	1577.	1422.	1531.	1441.	1511.	1476.	1617.	1400.		1197.	639.	
601.2	24.40	1578.	1426.	1534.	1444.	1512.	1479.	1615.	1402.		1217.	654.	

1. Tabulated Data

ARO, INC. - AEDC DIVISION
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ARNOLD AIR FORCE STATION, TENNESSEE
NASA/AMES AFRSI MATERIALS TEST

DATE COMPUTED 4-MAY-79
TIME COMPUTED 14:48:29
DATE RECORDED 6-APR-79
TIME RECORDED 4:10: 7
PROJECT NUMBER V41C-56

50 INCH HYPERSONIC TUNNEL C

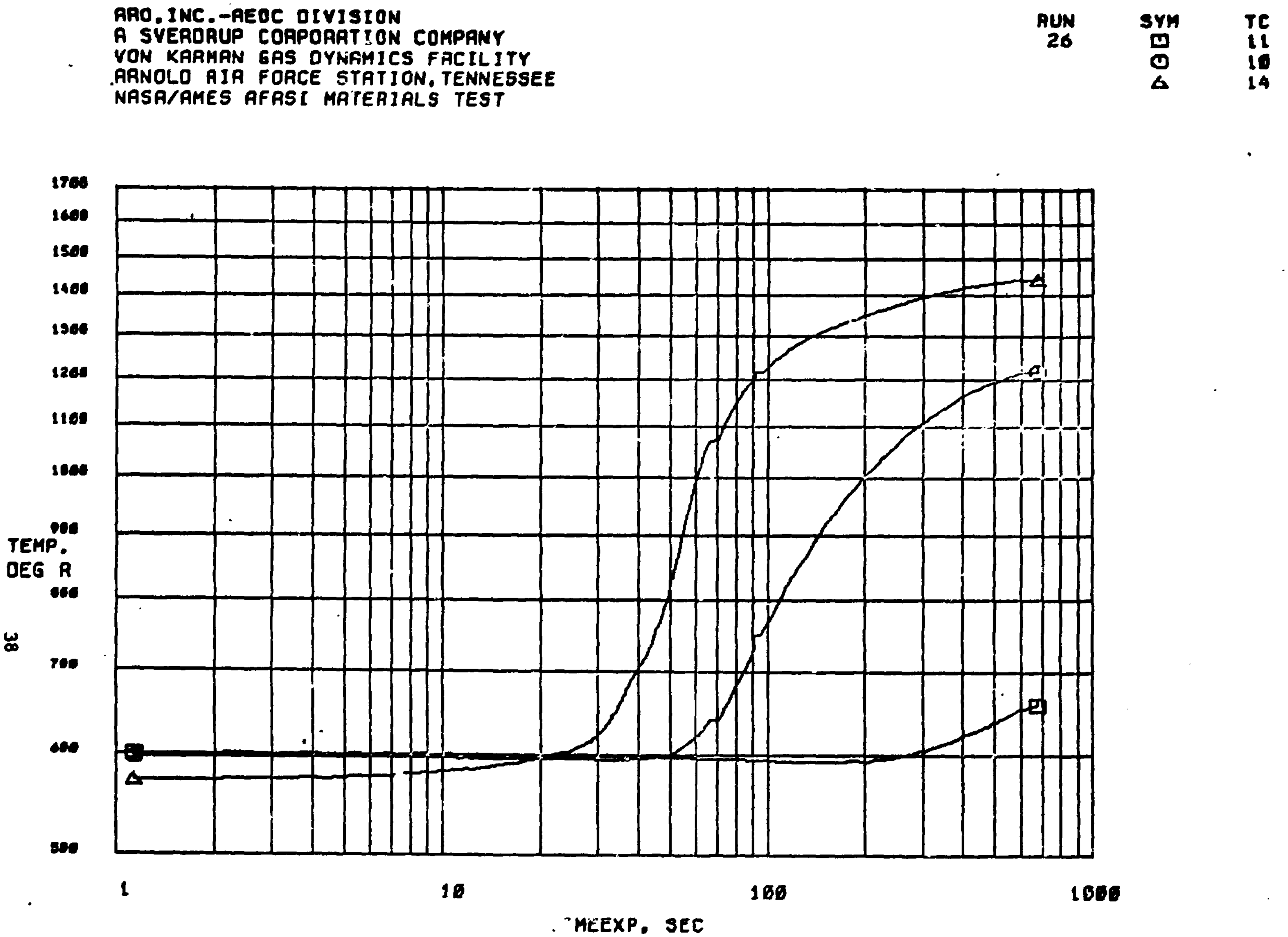
PAGE 2

RUN	CONFIG NUMBER	SAMPLE POSITION	M NUMBER	PT,PSIA	TT,DEG R	ALPI (DEG)	PHII (DEG)	CR (INCHES)
26	2	0	10.14	1194.90	2142.7	11.60	199.88	25.00

T (DEG R)	P (PSIA)	Q (PSIA)	V (FT/SEC)	RHO (LBM/FT3)	MU (LBF-SEC/FT2)	RE (FT-1)	ITT (BTU/LBM)	TIMEINJ (SEC)	TIMECL (HOUR MIN SEC MSEC)	TIMEEXPT (SEC)
105.7	0.024	1.739	5109.8	6.172E-04	8.503E-08	1.193E+09	5.457E+02	6.91	4 10 35 232	680.26

WEDGE ATTITUDE AND TEMPERATURE HISTORY

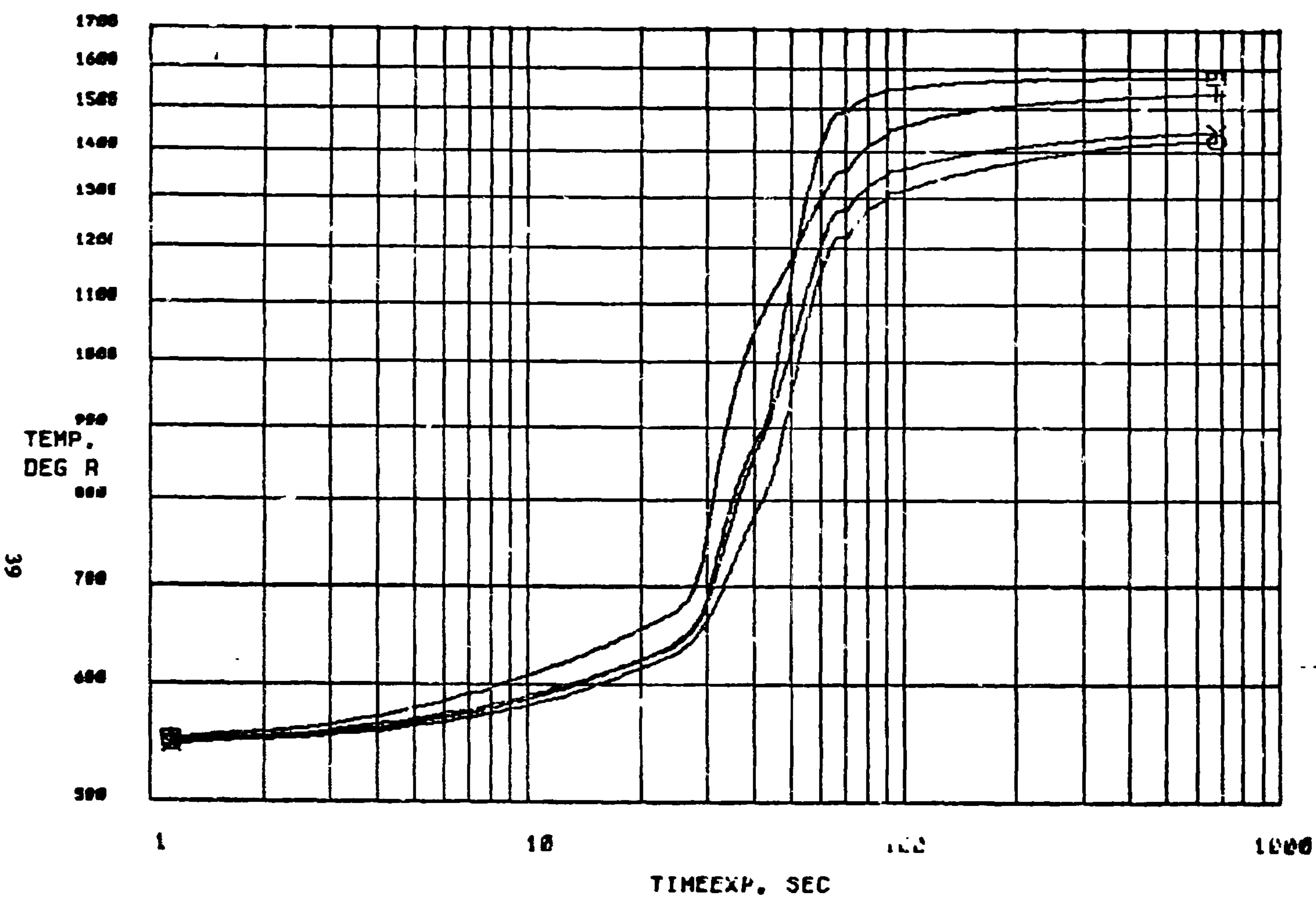
TIMEEXP (SEC)	WA (DEG)	TC13 (DEGR)	TC14 (DEGR)	TC15 (DEGR)	TC16 (DEGR)	TC17 (DEGR)	TC18 (DEGR)	TC19 (DEGR)	TC20 (DEGR)	TC21 (DEGR)	TC22 (DEGR)	TC23 (DEGR)	TR1 (DEGR)	TR2 (DEGR)	AMES SENSOR (MV)
1.1	0.36	595.	572.	534.	530.	534.	536.	542.	593.	546.	554.	565.	592.	591.	0.000
2.1	0.42	595.	573.	539.	538.	540.	543.	549.	593.	562.	562.	571.	592.	590.	0.065
3.1	0.40	595.	573.	544.	543.	549.	550.	556.	593.	569.	568.	575.	592.	590.	0.095
4.1	0.40	595.	573.	549.	550.	558.	559.	564.	594.	575.	575.	582.	592.	590.	0.130
5.1	0.40	595.	576.	556.	558.	568.	567.	571.	593.	582.	582.	590.	592.	590.	0.170
6.1	0.39	595.	576.	560.	564.	576.	577.	580.	594.	587.	589.	597.	592.	590.	0.210
7.1	0.39	594.	578.	566.	570.	584.	585.	586.	593.	594.	597.	604.	592.	590.	0.245
8.1	0.39	595.	579.	572.	577.	593.	594.	593.	593.	600.	601.	610.	592.	590.	0.265
9.1	0.39	595.	580.	577.	582.	599.	602.	599.	593.	605.	608.	616.	592.	590.	0.310
10.1	0.39	594.	582.	582.	588.	607.	610.	605.	593.	610.	615.	622.	592.	590.	0.315
15.1	0.39	593.	589.	607.	614.	635.	645.	632.	592.	635.	642.	647.	591.	590.	0.470
20.1	0.39	593.	597.	630.	636.	660.	674.	654.	591.	656.	666.	669.	591.	590.	0.575
30.1	6.40	592.	622.	718.	766.	839.	783.	793.	591.	722.	745.	776.	591.	590.	1.065
40.1	6.96	592.	704.	920.	1092.	1088.	966.	1094.	590.	873.	961.	1103.	591.	590.	4.210
50.1	14.18	591.	816.	1065.	1244.	1329.	1098.	1259.	589.	1008.	1101.	1294.	591.	589.	5.920
60.1	24.26	591.	990.	1235.	1478.	1577.	1273.	1432.	587.	1172.	1274.	1533.	590.	589.	8.520
71.3	24.53	589.	1077.	1297.	1542.	1619.	1335.	1491.	587.	1247.	1336.	1587.	590.	589.	9.815
81.3	24.52	590.	1154.	1337.	1574.	1633.	1371.	1526.	587.	1301.	1374.	1612.	590.	589.	9.900
90.7	24.51	591.	1202.	1357.	1587.	1640.	1388.	1540.	586.	1326.	1390.	1623.	590.	589.	10.075
101.3	24.49	592.	1235.	1370.	1596.	1644.	1398.	1547.	586.	1341.	1399.	1630.	590.	588.	10.085
CAMERA NO. 1 TAKEN AT 121.3 SECONDS															
121.3	24.45	598.	1278.	1386.	1606.	1649.	1410.	1555.	588.	1359.	1412.	1639.	589.	588.	10.345
151.3	24.47	613.	1317.	1400.	1616.	1654.	1421.	1563.	598.	1378.	1424.	1648.	589.	588.	10.420
201.2	24.46	640.	1355.	1414.	1624.	1661.	1431.	1568.	618.	1390.	1435.	1656.	588.	587.	10.715
301.3	24.44	721.	1396.	1428.	1633.	1667.	1441.	1572.	677.	1406.	1446.	1664.	588.	587.	10.938
401.2	24.43	772.	1420.	1437.	1638.	1673.	1446.	1575.	727.	1415.	1452.	1671.	589.	587.	11.165
501.2	24.42	806.	1434.	1441.	1637.	1673.	1449.	1575.	765.	1419.	1455.	1673.	590.	588.	11.285
601.2	24.40	830.	1443.	1444.	1636.	1676.	1451.	1577.	792.	1422.	1457.	1676.	592.	590.	11.365

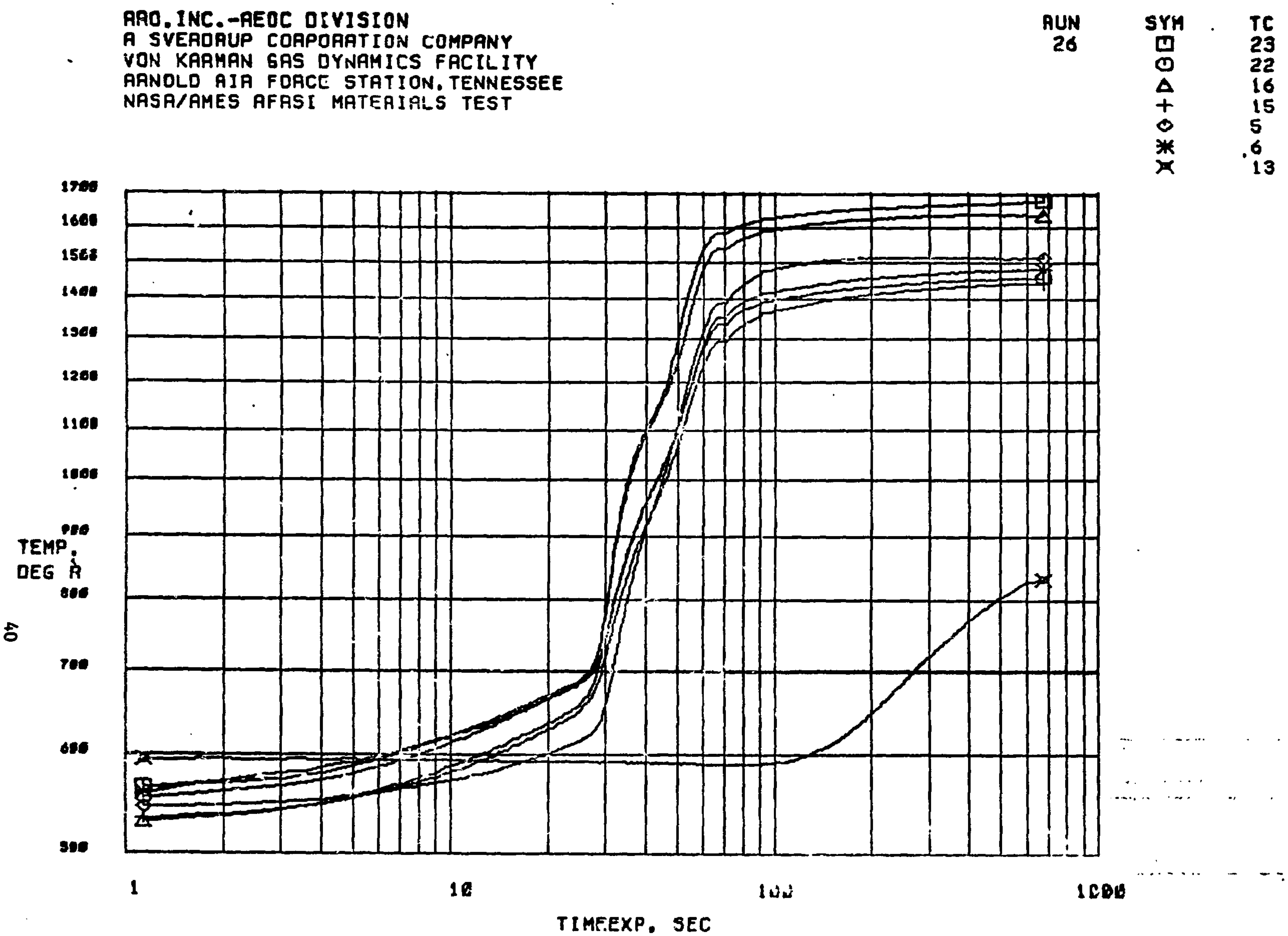


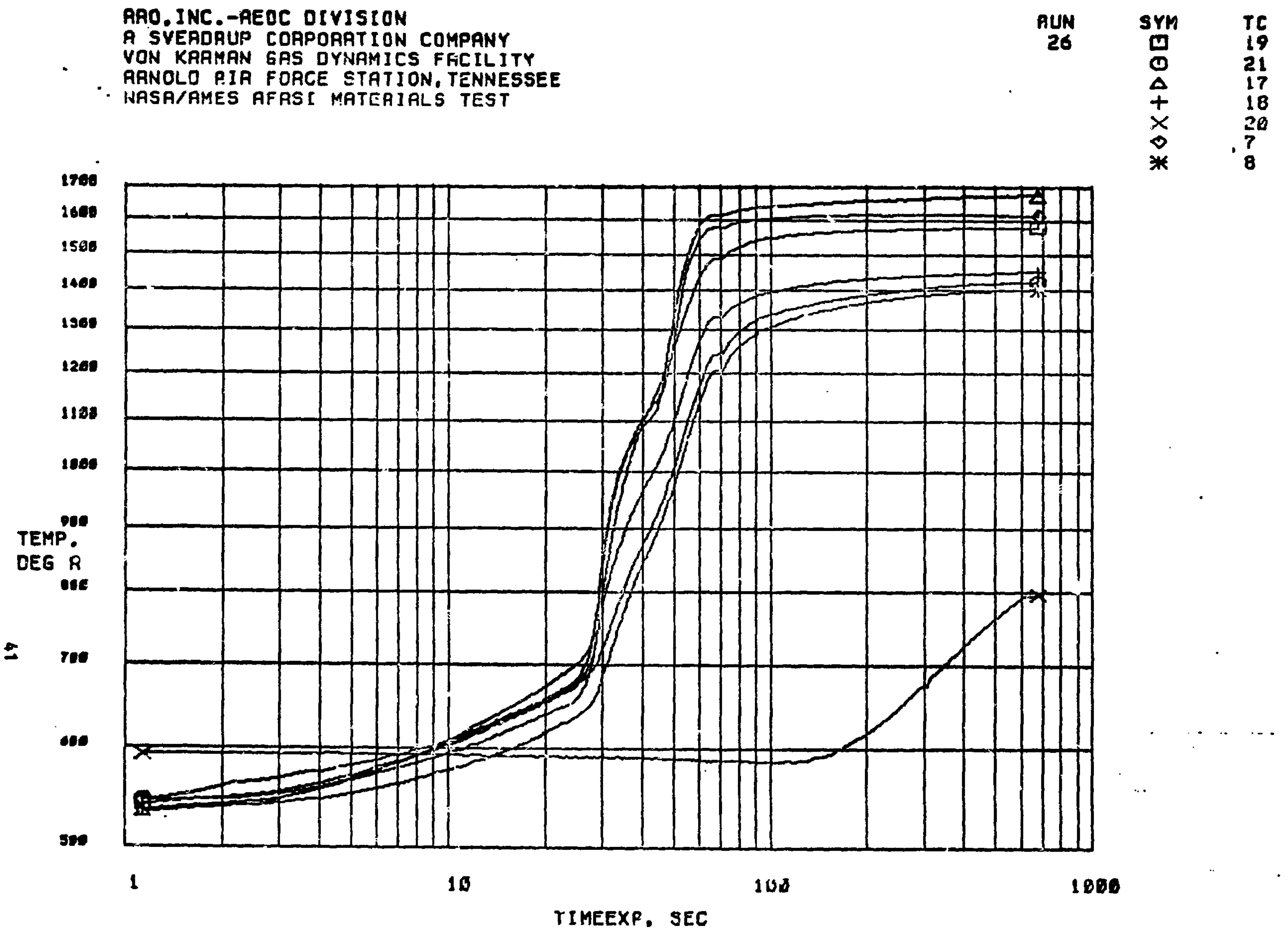
2. Plotted Data

ARO.INC.-AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/AMES AFRSI MATERIALS TEST

RUN	SYM	TC
26	⊟	1
	⊖	2
	+	3
	×	4




ARO, INC.-AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/AMES AFRSI MATERIALS TEST
RUN 26
SYM
TC
23
22
16
15
5
6
13
TEMP, DEG R
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
1
10
100
1000
TIMEEXP, SEC


ARO, INC.-AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/AMES AFRSI MATERIALS TEST
RUN 26
SYM
TC
19
21
17
18
20
7
8
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
TEMP, DEG R
1
10
100
1000
TIMEEXP, SEC

ARO, INC.-AEDC DIVISION
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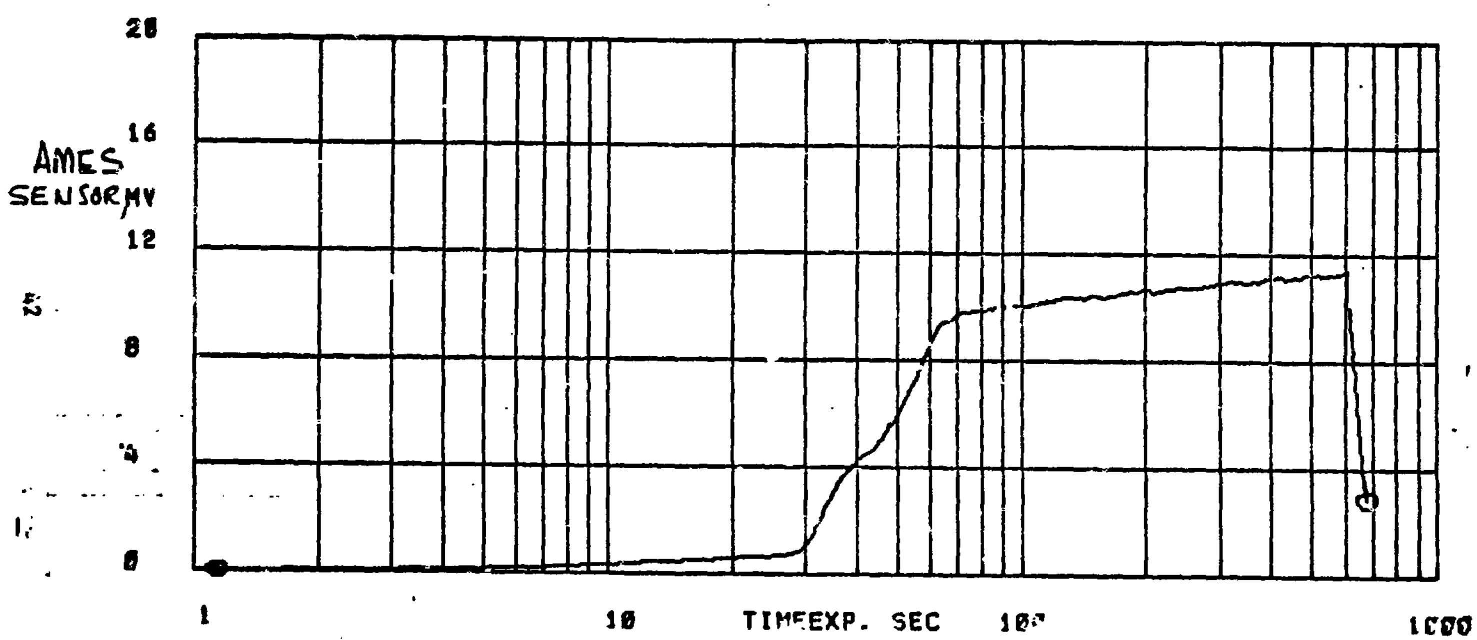
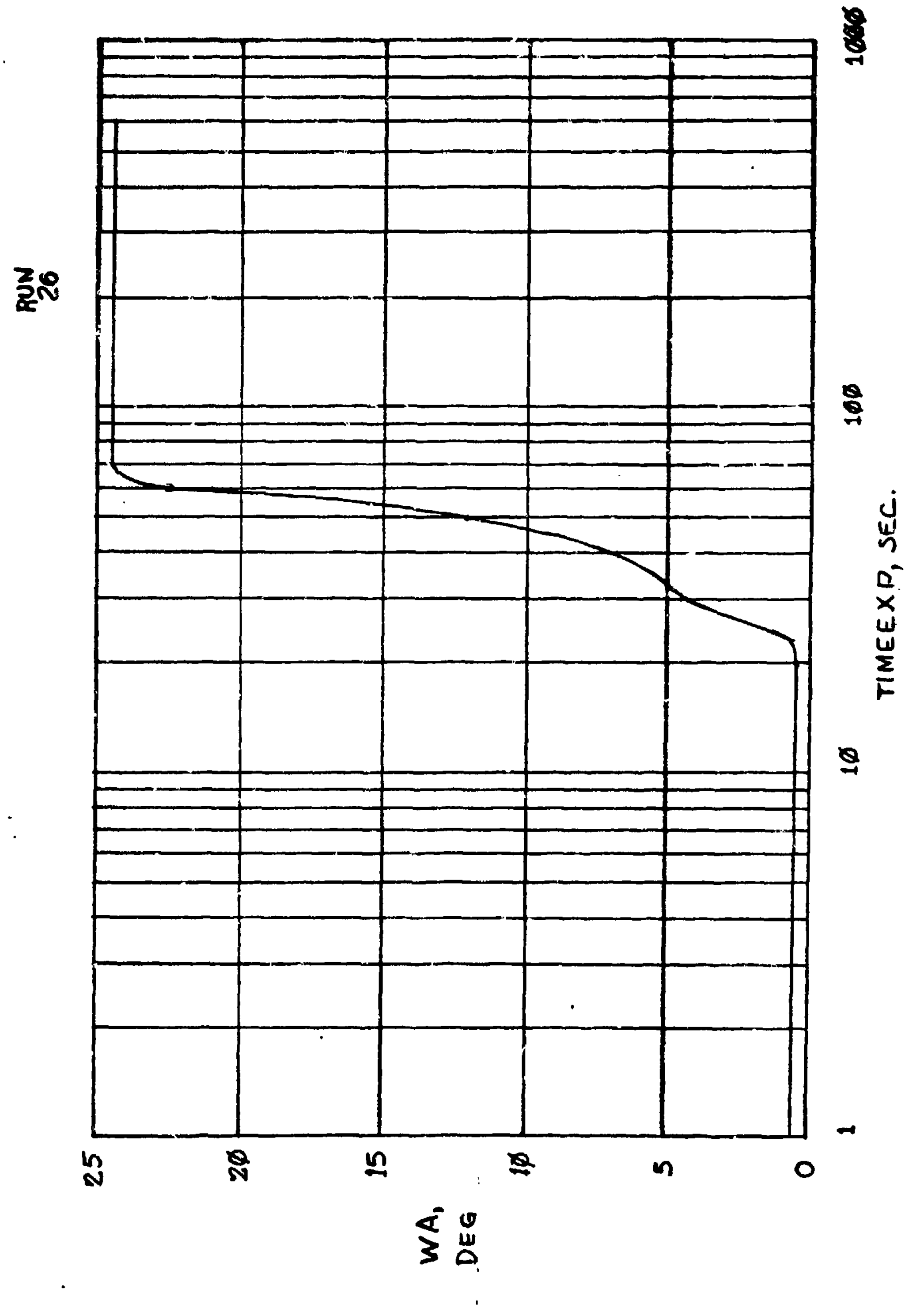
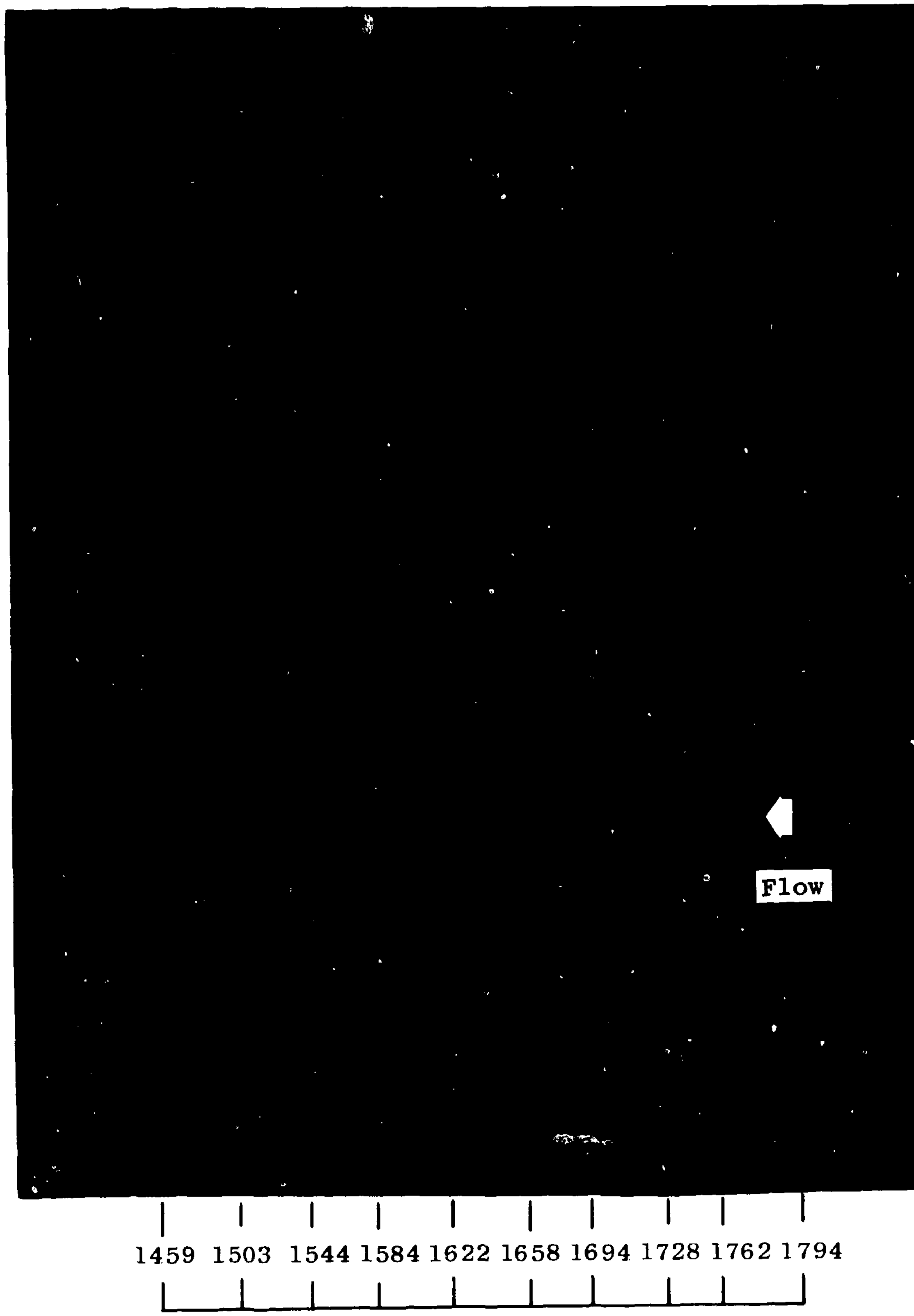
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/AMES AFRSI MATERIALS TEST

RUN 26 SYM SENSOR TC




RUN 26
WA, DEG
25
20
15
10
5
0
1
10
100
1000
TIMEEXP, SEC.



Color Bar Temperature Calibration
(from Table 2), °R

3. Typical IR Photograph of Surface Temperature